MECHANICAL ENGINEERING

INCLUDING THE ENGINEERING INDEX

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Pathfinders

"Stimulation of research and invention is essential to progress and prosperity." Thus Doctor Jacobus commences his Franklin Institute address which is the leading article in this issue. The great frontiers of civilization today are the boundaries between knowledge and ignorance, and upon the skill and perseverance of the pathfinders into the unknown depends the advancement of the well-being of mankind. Engineers have a vital interest in research, for along the trail blazed by the scientist they build the more permanent road. Doctor Jacobus' analysis of the functions of the various agencies for stimulating and conducting research therefore has a direct appeal to the engineer.

OCTOBER 1924

THE MONTHLY JOURNAL PUBLISHED BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Mechanical Engineering

The Monthly Journal Published by

The American Society of Mechanical Engineers

Publication Office, 207 Church Street, Easton, Pa. Editorial and Advertising Departments at the Headquarters of the Society, 29 West Thirty-ninth Street, New York

Volume 46 | October, 1924 | Number 10

CONTENTS OF THIS ISSUE

DEPARTMENTAL

ADVERTISING

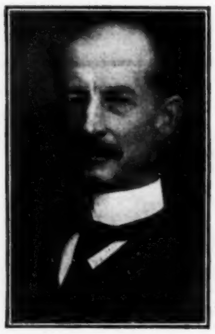
Price 60 Cents a Copy, $5.00 a year: to Members and Affiliates, 50 Cents a Copy, $4.00 a year. Postage to Canada, 75 Cents Additional; to Foreign Countries $1.50 Additional. Changes of address should be sent to the Society Headquarters.

Entered as second-class matter at the Post Office at Easton, Pa., under the Act of March 3, 1879.
Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on January 17, 1921.

P. Heymans

R. H. Heilman

F. V. Smith



D. S. Jacobus

Eskil Berg

A. H. Armstrong

Contributors to this Issue

Dr. D. S. Jacobus, who contributes the leading article in this issue on Stimulation of Research and Invention, acts as advisory engineer for the Babcock & Wilcox Co., New York. Upon his graduation from Stevens Institute of Technology he was appointed instructor and then assistant professor of experimental mechanics and in 1897 the full professorship in that subject and engineering physics was conferred upon him. Doctor Jacobus served in this capacity until 1906 when his relationship with the Babcock & Wilcox Co. began. At that time he received from Stevens Institute the honorary degree of Doctor of Engineering. He has written many scientific papers on engineering subjects and has been exceedingly active in engineering societies, especially in The American Society of Mechanical Engineers which he served as president in 1915–16 and previously as manager and vice-president.

* * * * *

Eskil Berg and **Frank V. Smith,** coauthors of the paper on Modern Tendencies in Steam-Turbine Power Plants, are both connected with the General Electric Co.

Mr. Berg has been actively engaged in the design and development of turbine and electrical machinery for the past thirty years. From 1898 to 1905 he was assistant to Dr. C. P. Steinmetz and since that time has been associated with W. L. R. Emmet, consulting engineer of the company. He was born in Ostersund, Sweden, and received his early education in the Chalmers Institute at Gothenburg.

Mr. Smith is a member of the marine-engineering department of the company. He was formerly instructor in the Marine Schools conducted at the plant as a part of the war-emergency program for the intensive training of chief engineers in the operation of turbine ships. He was born in Sacramento, Cal., where he received his early education, and during the War served with the U. S. Navy. He resigned in 1920 to become attached to the above department.

* * * * *

Albert H. Armstrong, assistant engineer of the railway department, General Electric Co., author of the paper in this issue on The Development of the Electric Locomotive, was born in Worcester, Mass. He was graduated from the engineering course of Worcester Polytechnic Institute in 1891 and in the same year entered the employ of the Thomson-Houston Co., Lynn, Mass. When the General Electric Co. was organized in 1894 Mr. Armstrong started work at Schenectady on design under the direction of Doctor Steinmetz. In 1897 he became connected with the railway department and has since devoted most of his time to the study of railway problems. He is chairman of the electrification committee of the company.

* * * * *

R. J. S. Pigott, author of the paper in this issue on Combustion Control for Boilers, is mechanical engineer of Stevens & Wood, Inc., New York, in charge of power-station and industrial-plant design. Mr. Pigott was graduated from the school of mechanical engineering, Columbia University in 1906. For three years he served as professor of steam engineering at Columbia, resigning to become consulting engineer and power superintendent of the Remington Arms-Union Metallic Cartridge Co. He has served also as consulting engineer for the Sanford Riley Stoker Co., and as superintendent of mills of the Bridgeport Brass Co. From 1920 to 1922 Mr. Pigott was works manager of the Crosby Steam Gage & Valve Co.

* * * * *

Paul E. Holden, who writes an article on The New Conservation is assistant manager of the Department of Manufacture, Chamber of Commerce of the United States. Mr. Holden was educated in the schools of Indianapolis, Indiana, later receiving a B.S. Degree in mechanical engineering from Purdue University. During the war he served as Captain in the Small Arms Division of the Ordnance Department, U. S. Army. His business connections have been with E. C. Atkins & Co., saw manufacturers, Remington Typewriter Co., and the Library Bureau Co., in production and industrial-engineering work.

* * * * *

Paul Heymans, author of the article on Mathematical Theory of Dynamic Stresses in Rotating Gear Pinions, was born in Ghent, Belgium. From 1913 to 1920 he attended the University of Ghent and L'Ecole spéciale des Travaux Publics in Paris, receiving the degree of Doctor in Engineering Science. The year 1920–21 he spent as a fellow of the C. R. B. Educational Foundation at the Massachusetts Institute of Technology, where he received the degree of D.Sc. He is now assistant professor in the physics department of M.I.T.

* * * * *

R. H. Heilman, who writes on Heat Losses Through Insulating Materials, received his professional education in the School of Engineering, University of Pittsburgh, where he received his B.S. in electrical engineering and in 1922 his E.E. Since 1918 Mr. Heilman has been engaged in research on heat transmission at the Mellon Institute of Industrial Research of the University of Pittsburgh, where he now holds the Industrial Fellowship on Heat Insulation.

* * * * *

C. A. Beckett, author of the paper on Foreign Progress on Cutting Metals, is associate in mechanical engineering, Columbia University, in charge of courses pertaining to shop processes and machine-tool operation. Mr. Beckett was born in Haverhill, Mass., where he was educated. He has been connected with the United Shoe Machinery Co., Westinghouse Electric & Manufacturing Co., and the Ingersoll-Rand Co.

Management Week—October 20–26, 1924

Sixty-five cities are planning to hold Management Meetings during the week of October 20. Local clubs are joining with The American Society of Mechanical Engineers, the American Management Association, the National Association of Cost Accountants, the Taylor Society and Society of Industrial Engineers, to make this week a successful one. See the current issues of the *A.S.M.E. News* for details.

MECHANICAL ENGINEERING

Volume 46 October, 1924 No. 10

Stimulation of Research and Invention

Address at Inauguration Exercises of Bartol Research Foundation Analyzes Administration of a Research Foundation and Problems of Patent Right and Coöperation

By Dr. D. S. JACOBUS,[1] NEW YORK, N. Y.

STIMULATION of research and invention is essential to progress and prosperity. There could be no more fitting opportunity to say something on this subject than at the Centenary Anniversary of an institution that has been preëminent in encouraging scientific effort, and in connection with the inauguration of a Research Foundation established for the purpose of encouraging research. The Franklin Institute has accomplished much along the very lines for which the work of the Bartol Research Foundation will form a part, and is eminently fitted for handling this trust in a field in which it has already been successful.

Success in research usually comes from the individual. While this may not wholly apply in some cases of coöperative research, it holds in the great majority of cases. In this respect research is akin to invention. Progress in research can in most cases be best accomplished by the encouragement of the individual. It is in inspiring and encouraging the individual to put forth scientific effort that The Franklin Institute has played a most important part. It is therefore a happy coincidence that on the one hundredth anniversary of the birth of a society that has done so much in inspiring effort it is given an added opportunity through having funds at its disposal for doing good in its chosen field.

It is no easy matter to properly administer a research fund. There are two lines of usefulness, the promotion of research and the conduct of research. The coördination of effort to avoid duplication has been under discussion by Engineering Foundation and by the Engineering Division of the National Research Council. Engineering Foundation is a trust fund for the furtherance of research in science and engineering established by Ambrose Swasey by gifts to the United Engineering Society. The National Research Council is organized under a Congressional Charter of the National Academy of Sciences. These organizations coöperated during the war and much useful work was accomplished. While there cannot be an exact dividing line between the fields of work of organizations so closely akin and having mutual interests, it would seem that foundations such as the Engineering Foundation and the Bartol Foundation could do the most good by expending their available funds on the conduct of research, not, of course, by actually doing or directing the research work, but by providing means for assisting those that are actually doing or directing the work. It is a difficult task to accomplish this to the best advantage and no hard and fast rules can be laid down.

Research and invention go hand in hand. The question will come up of whether the party who is assisted by a foundation will be allowed to patent a development. While this question may not be of importance in connection with the work of the Bartol Foundation in view of its purely scientific character, it is important in connection with research in general and will be discussed. There is also the question of publicity and whether the results of work that is done shall be made available to the public, which in some cases might interfere with the patenting of an invention. These with other troublesome questions, such as what cases should receive assistance, will always require careful investigation and mature judgment before arriving at a decision. There is many a striving professor who, should he be able to secure funds for conducting research work without signing off all right and title to the outcome of his efforts, would be willing to contribute his own time free of charge. The striving professor is only one of a type that should be helped.

To search out an individual of promise and to appropriate the proper amount of money for any particular research requires exceptional ability. The better qualified those who are handling a fund, the fewer the rules need be. Many are working on the problem of how a research fund should be administered and it would be presumptious for any single individual to propose rules except for general discussion. It is in this spirit that the following is suggested.

1 Encourage research of a scientific character which will be generally useful. Most researches of this kind have specific objects in view and do not lead to inventions except as an incidental result of some feature bearing on the research.

2 Make no general restrictions respecting the patenting of inventions. Success in research comes through incentive as much as through initiative, and should an investigator be so fortunate as to develop something that is patentable and to secure a valuable patent, this will serve a most useful purpose in stimulating and encouraging others.

3 Require periodic reports which will be held in confidence. Do not insist on publication in all cases. Insist that no matter be published except by the mutual consent of the party doing the research and of the foundation.

4 Do not grant money for aimless research, but do not expect all researches to result in valuable contributions. Those who have strived to solve the secrets of nature know only too well that a new start must often be made and much matter discarded.

Applying the Golden Rule and treating the party conducting a research in the way those administering the fund would like to be

[1] Advisory Engineer, Babcock & Wilcox Co. Past-President, A.S.M.E.

Delivered at the inauguration exercises of the Bartol Research Foundation which were a part of the Centenary celebration of the founding of The Franklin Institute of Pennsylvania, held in Philadelphia, Pa., September 17, 18 and 19.

The Franklin Institute was organized in 1824 to meet a demand in America for an institution which would be not only an appropriate memorial to the name of Franklin, but also a means of continuing for all time a work which throughout his long life he regarded as his best, namely, the discovery of physical and natural laws and their application to increase the well-being and comfort of mankind.

The work and accomplishments of the Franklin Institute have been numerous and varied. Much of the information on early American patents is found in the pages of the *Journal of the Franklin Institute*, a monthly publication undertaken in 1826 under the editorship of Dr. Thomas P. Jones, then professor of mechanics in The Franklin Institute. The library of the Institute, consisting of over eighty thousand volumes and more than twenty thousand pamphlets, was established in 1827. The Committee on Science and the Arts of sixty members investigates discoveries, processes and inventions and makes the following awards: Franklin Medal, Elliott Cresson Medal, Howard N. Potts Medal, Louis Edward Levy Medal, Edward Longstreth Medal, Certificate of Merit, and Boyden Premium. The Institute has given free to the public thousands of lectures by distinguished lecturers, and has held exhibitions of American manufactures from time to time, the first being in 1824. An especially notable electrical exhibition in 1884 was made international in character by an Act of Congress, and was the first exhibition in America devoted exclusively to the electrical arts. The Institute also owns a valuable collection of models and historical apparatus.

The Bartol Research Foundation was established in 1921 by a bequest to The Franklin Institute of sufficient funds to carry on its researches, by Henry W. Bartol, a life member of the Institute, for the purpose of conducting researches relating to fundamental problems in physical science, particularly those in the field of electricity, and for the investigation of specific problems of a scientific nature which may arise in industry. Dr. R. B. Owens was appointed Director of the Foundation. In 1923 a laboratory for conducting the work of the Foundation was provided for by the reconditioning of three buildings on the Institute's property at Nineteenth and Cherry Streets, Philadelphia.

treated will give the very best results. With a broad policy those having a fund in charge require the services of a true physicist having that power of perception which will enable him to correctly pick his men. This means the securing of an exceptional man. Such a man cannot be bought by offering a high salary, he must be sought and found and if he has the right capabilities his value to the foundation will far exceed anything he may be paid. In any event care should be taken to conform with safe and sane business principles and to keep the expense of administering a fund in line with what it should be in proportion to the amount expended in actual research.

The most useful research work may not lead to invention; for example, Engineering Foundation and National Research Council coöperated with others in the work that was done by Prof. H. F. Moore at the Experiment Station at the University of Illinois on the fatigue phenomena of metals. This investigation led to results that are useful to engineers at large and represents a class of work that should surely be encouraged. Another research respecting which there can be no question as to whether it should receive encouragement is that which is being carried on under the auspices of The American Society of Mechanical Engineers to obtain a more exact steam table and one giving values for the higher pressures and temperatures. A number of industrial organizations have contributed toward the expense of making the tests and Engineering Foundation has endorsed the movement by making a contribution. In this investigation none of those in charge of the work receives any recompense, all of the money collected being expended either in making the apparatus or in the actual conduct of the tests. Dr. Harvey N. Davis of Harvard University has supervised the making of a number of tests at the Jefferson Laboratory to determine the Joule-Thomson effect over a large field. Dr. Frederick G. Keyes at the Massachusetts Institute of Technology is supervising the measurement of the pressure, temperature, and volume figures in the saturated as well as the superheated region with a special apparatus of his design. Dr. N. S. Osborne at the U. S. Bureau of Standards is in charge of the determination of the thermal capacity of water as saturated liquid. A research foundation would be fortunate in securing work of this kind to foster.

Mention has been made of coöperation in research. It is only through coöperation that the best progress can be made in certain classes of research. This was exemplified during the war when some of the very best and most useful research work was done by the laboratories of large corporations. A great deal of research is done under the direction of corporations which have specific objects in view and valuable as this is, it must be supplemented by individual research in order to have well balanced scientific progress.

Where there is coöperation in research it is often hard to say who is the inventor in case of a development. The same applies to the work of any industrial organization. The party who first conceives a way or method of doing a thing, and puts it into tangible form, is technically the inventor, whereas had he not been working with others his mind might not have been directed along the particular channels that led to the invention. There are few valuable inventions that have been developed by parties working alone. When working with others most inventions come through the following up of a line of thought in which many have taken part. There is often a tendency for the inventor to overlook this feature and feel that through being the one to patent an idea he should receive an undue amount of credit or compensation. The same applies to any successful issue in research work whether it is patentable or not.

There should be a distinction between a patent on an improvement that was the object of a research and a patent that is an incidental result of some general research. Where a research worker is given a very definite problem of improving, for instance, some existing thing, he should not be permitted to patent such an improvement with a view of deriving extraordinary benefit from something which he was definitely employed to do. It may be desirable to take out patents in a case of the sort in order to prevent designing people from securing patents for their own benefit on certain features of the work and thereby defeat the very object of the work. The publication of articles and reports which are of necessity general in their presentation can not be depended upon to act as an anticipation in the same way that a patent does, and there is therefore considerable risk that once the general results of a research are known designing people will endeavor to secure patents on some of the features. Where patents are taken out on an improvement of the sort a definite arrangement should exist with the research worker by which the patent can be made public either by dedication by the inventor or by the research foundation which provided the facilities.

Where the problem is a general investigation of a large mass of phenomena, or where the research worker is working on a problem of his own making, then, if in connection with such an investigation he makes an invention which may have come to his mind merely as an incident to his general work, he should have the right to patent the invention as his own. Even though this feature may be an embarrassing one which may call for a number of special rulings, I firmly believe that in general there should be no restriction put on the worker respecting the patenting of anything he may develop, and that any feature of an investigation that can be patented should be patented, because if this is not done some unprincipled person may endeavor to take advantage of the opportunity to secure a patent of his own.

Research foundations may be made useful in avoiding as far as possible the duplication of research, but an attempt should not be made to go too far in directing research. To secure the best results an ambitious worker must have a free hand and it is this type of worker that should be given encouragement and assistance.

The Purpose of Science[1]

SCIENCE is classified knowledge, no more, no less. The cardinal principle of science is that we know nothing until men find it out. There is no authority under heaven or above it that can give answers in advance to any question of fact. "*Roma locuta est, causa finita est,*" closes no scientific investigation. Science is human experience, tested and verified by our instruments of precision, telescope, microscope, scalpel, spectroscope, and those finer instruments of the mind itself, memory, logic and mathematics. Once its facts are obtained, they must be set in order. They must show relations of cause and effect, else they lead nowhere. "Facts are stupid things," Agassiz used to say, "unless they can be combined into truth," and to become truth facts must be stated in terms of human experience.

Science is only common sense expanded and verified and applied to a wider range of objects. With its instruments of precision (mind, memory, logic, mathematics, and its accessory tools) it goes beyond the obvious into the hidden complexities of truth. The final test of truth is its "livableness," the degree to which we may trust our lives to it or to the methods by which it is won. It is not merely "workableness," for an idea false or incomplete may be workable in a degree.

The purpose of science is in the main threefold: first, to help humanity by its control of sanitation, conservation, and the use of the forces of nature—this is applied science; second, to furnish a sound basis for the conduct of life—this is the art of ethics, and right living can fall back on no other authority.

The third function of science is to widen the human mind. Its span is the universe, dealing as well as may be with the infinite great as with the infinite little. We can reach a small part, not a fraction but a tangible fringe of a universe in which there is neither great nor small. We find in it endless change, but every change is orderly. So far as we can see "nothing endures save the flow of force and the rational intelligence that pervades it." This intelligence we cannot describe, nor circumscribe. We cannot speak of it in any terms of human experience, and to try to do so shows only the narrowness of our conception. These words are attributed to Mencius in China thirty centuries ago. "He will appear without showing Himself, effect renovation without moving, create perfection with acting. It is the law of heaven and earth whose way is solid, substantial, vast and unchanging."

[1] An excerpt from an address delivered June 26, 1924 by David Starr Jordan, then president of the Pacific Division of the American Association for the Advancement of Science. The complete address appears in *Science*, for June 27, 1924.

Modern Tendencies in Steam-Turbine Power Plants

High Pressure, Superheat, Reheating, and Steam Extraction as Affecting Power-Plant Economy, and the Advantages Obtained in Their Adoption for Marine Propulsion

By ESKIL BERG[1] AND FRANK V. SMITH,[1] SCHENECTADY, N. Y.

I—MODERN TENDENCIES IN STEAM-TURBINE POWER PLANTS

The importance of the adoption of high steam pressure, high steam temperature, reheating of steam, and steam extraction is probably best illustrated by the fact that today in this country we are building six large central power stations in which all these features have been adopted. Chicago for instance, is now building a station which will consist of two 50,000-kw. turbines and one 60,000-kw. turbine, which will be operated at 600 lb. boiler pressure, 700 deg. fahr. steam temperature. The steam will be reheated at approximately 100 lb. pressure to 700 deg. fahr., and the feedwater will be heated to approximately 300 deg. fahr. by extracting steam from the turbine.

The American Gas and Electric Company is building three different stations. In one the initial installation will consist of four 35,000-kw., 1800-r.p.m. turbines, and the other two stations will each have two 35,000-kw. turbines; all to be operated under steam conditions similar to those at Chicago. The Columbia Gas and Electric Company is building one station where the initial installation consists of two 40,000-kw., 1800-r.p.m. turbines which will also be operated under these same steam conditions.

The Edison Illuminating Company of Boston, in the new Weymouth Station, is installing one large boiler with 1200-lb. pressure, 725-deg. steam, and a 3500-kw. turbine which will take steam at 1200 lb. pressure and 725 deg. and exhaust it into the main steam line of 350-lb.-pressure and 725-deg.-temperature steam. This high-pressure boiler for the Weymouth Station is designed to handle 130,000 lb. of steam per hour.

Improvements in the Steam Turbine

The steam turbine today has reached a point of development where its efficiency is within a few per cent of that theoretically obtainable, so that further improvements in the turbine itself cannot materially reduce the fuel consumption. We must therefore consider the steam condition itself; and this is why central-station managements all over the world today are looking toward improved steam conditions.

It can readily be seen that the more energy (B.t.u.) there is supplied to each pound of steam when it enters the turbine, the fewer pounds will be required to produce the unit of power (kilowatt-hour). To supply more energy to a pound of steam the temperature must be raised. This can be done either by raising the steam pressure, adding superheat, or doing both. Steam can also be extracted from the turbine at some lower pressure, reheated, and then led back to the turbine.

Fig. 1 shows graphically how the energy of a pound of coal is distributed in a first-class power station using 250 lb. pressure and 200 deg. fahr. superheat under good vacuum conditions. This shows that 20 per cent of the energy in the coal is converted into electrical energy, corresponding to 17,075 B.t.u. per kw-hr., which is about the lowest figure at which power has been produced under these steam conditions. It will also be noted that the condenser loss is by far the largest loss, being 55.29 per cent of the heating value of the coal. With this diagram in view, it will easily be understood that the better the steam consumption per kilowatt-hour, the less steam goes to the condenser. Consequently, the condenser loss is reduced in the same proportion.

Only a few years ago it was considered good practice to be able to produce a kilowatt-hour with 14 lb. of steam going to the condenser. Today, with the adoption of high steam pressure and superheat, reheat, and bleeding the turbine for heating the feedwater, this figure has been more than cut in half, which means that the condenser loss is practically cut in half.

Gain by Using High Steam Pressure

The total heat of steam gradually increases with the pressure until it reaches its maximum at 370 lb. abs.; it remains constant up to 395 lb. abs., and from there on it decreases. At 1200 lb. pressure the total heat is only 1179.7 B.t.u., which is the same as at 62 lb. abs. (Goodenough's steam table).

Table 1 shows the theoretical gain by raising the steam pressure. A pressure of 200 lb. has been used as the starting point and the available energy is given when one pound of steam is expanding

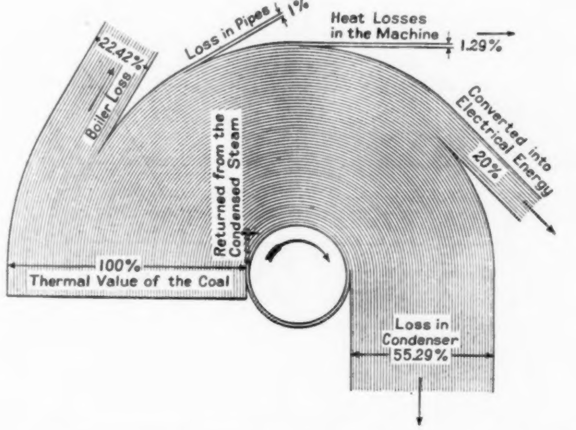


Fig. 1 Distribution of Energy of a Pound of Coal in First-Class Power Station

(Steam conditions: 250 lb., 200 deg. superheat, good vacuum.)

adiabatically down to 28.5 in. vacuum. It will be seen that by raising the steam pressure from 200 to 1200 lb., the total heat has been reduced from 1198.5 to 1179.7 B.t.u., or 1.58 per cent, while

TABLE 1 THEORETICAL GAIN BY RAISING STEAM PRESSURE

Absolute pressure, lb. per sq. in.	Corresponding temperature, deg. fahr.	Total heat, B.t.u. per lb.	Increase initial heat, per cent	Available energy, ft-lb., expansion to 28.5 in. vacuum	Increase of available energy per cent	Net gain in fuel, per cent
200	381.9	1198.5	...	272,000	...	...
300	417.5	1201.9	0.28	293,000	7.72	7.44
400	444.8	1202.5	0.33	304,500	11.95	11.62
500	467.2	1201.7	0.27	312,000	14.7	14.43
600	486.5	1199.8	0.11	319,000	17.2	17.09
700	503.4	1197.4	—0.092	323,000	18.7	18.79
800	518.5	1194.4	—0.342	327,000	20.2	20.54
900	532.3	1191.1	—0.617	329,000	20.9	21.51
1000	544.9	1187.6	—0.909	331,000	21.7	22.6
1100	556.6	1183.8	—1.225	335,000	23.2	24.42
1200	567.7	1179.7	—1.58	327,000	24.00	25.58

the energy has been increased from 272,000 to 337,000 ft-lb., or 24 per cent, a net gain of 25.5 per cent.

High Superheat

The theoretical gain by the use of superheat is almost negligible, as will be seen by Table 2. There is, however, a practical gain in its adoption which makes superheat necessary. It is clear by looking at the entropy diagram, Fig. 2, that the moisture in the exhaust increases as the initial pressure is increased. Moisture in a turbine affects its efficiency very much and is its greatest source of loss.

---

[1] General Electric Co.

Presented at a meeting of the Metropolitan Section of the A.S.M.E., New York, April 1, 1924. Part I prepared by Mr. Berg; Part II by Mr. Smith.

TABLE 2 THEORETICAL GAIN BY USE OF SUPERHEAT: INITIAL PRESSURE, 250 LB.; VACUUM, 28.5 IN.

Superheat, deg. fahr.	Temperature, deg. fahr.	Available Heat, deg. fahr.	Corresponding ft-lb.	Total heat, B.t.u. per lb.	Per cent increase in fuel to produce superheat	Per cent increase available energy due to superheat	Net theoretical gain, per cent	Decrease in water rate, per cent	Actual gain, per cent
0	406	369.9	288,000	1201.1	...	...	..	..	..
50	456	381.4	297,000	1233	2.66	3.11	0.45	4	1.34
100	506	393.5	306,000	1264	5.25	6.38	1.14	8	2.75
150	556	405.9	316,000	1292	7.57	9.74	2.17	12	4.43
200	606	418.7	326,000	1320	9.90	13.22	3.32	16	6.10
250	656	431.8	336,500	1346	12.08	16.75	4.67	20	7.92
300	706	445.3	347,000	1374	14.40	20.4	6.00	24	9.6

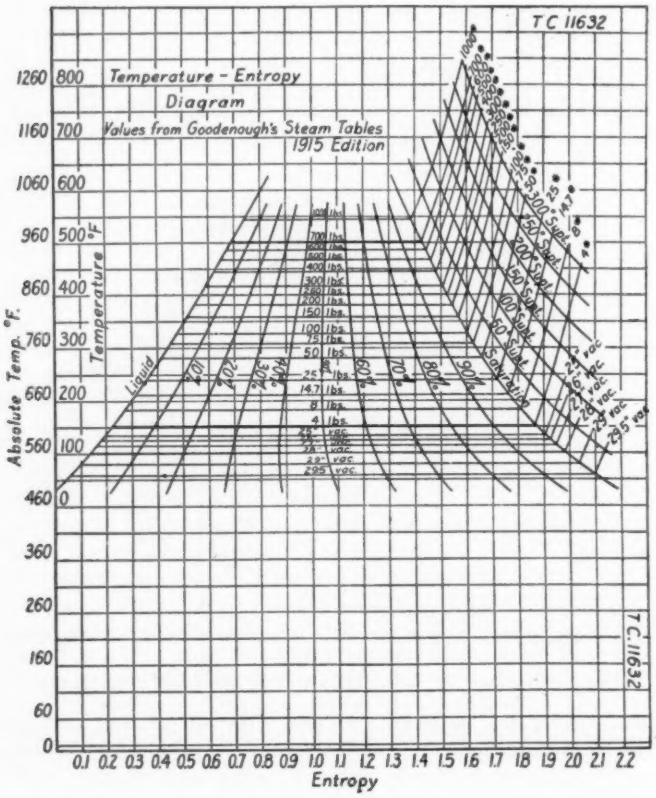


Fig. 2 Temperature-Entropy Diagram for Steam
(Goodenough's tables.)

The losses in an average, well-designed turbine of the impulse type, when dry initial steam is used, are of the following magnitude:

	Per cent
Loss due to friction in nozzles and blades, and windage loss of disks and blades	20
Steam leakage loss	3
Rejected energy (due to residual steam velocity)	3
Bearings, packings, etc.	1
Total loss	27
Efficiency of turbine	73

It will be seen that the first item is by far the largest and the moisture in the steam in all the stages has greatly increased this loss. If on the other hand, steam instead of being dry had entered the turbine with 200 deg. of superheat, it would be found that this loss would be reduced from about 20 to about 15 per cent and the turbine efficiency would be increased from 73 to 78 per cent.

Fig. 3 shows a cross-section of a turbine having 10 stages and gives approximately the condition of the steam in all the stages. This turbine has 80 per cent efficiency and is supplied with steam at 250-lb. gage pressure, superheated 250 deg., and is exhausted into a 29-in. vacuum.

Table 3 gives a comparison of the condition of the steam in the various stages of the turbine when supplied with steam superheated 250 deg. and when supplied with steam initially dry.

Gain by Using High Steam Pressure and Superheat Combined

Fig. 4 gives the ratio of available B.t.u. in steam to the total heat in steam, giving credit for the heat in the condensate which is returned at a temperature of 90 deg. fahr.

Up to the present time the standard steam pressure for large power stations has been 250 lb., with superheat of about 200 deg. and a vacuum of 28.5 in. From the curve, 32.8 per cent of the heat is available. At the present time several large stations are being built in this country which have adopted 550 lb. and 725 deg. total temperature. From the curve, 36.9 per cent of the heat is available for these conditions. With the same turbine and boiler efficiency this would mean a saving of 12.2 per cent.

With 36.9 per cent of the total heat theoretically available for conversion into electrical energy, and assuming a turbine efficiency of 75 per cent and a boiler efficiency of 80 per cent, the efficiency of the plant without auxiliaries is $36.9 \times 0.75 \times 0.80 = 22.2$ per cent. As one kilowatt-hour = 3415 B.t.u., this corresponds to $3415/0.222 = 15{,}350$ B.t.u. per kw-hr., to which has to be added about 5 per cent for station auxiliaries, making it = 16,100 B.t.u.

Steam Extraction

A very large gain in efficiency is made in the cycle shown in Fig. 4

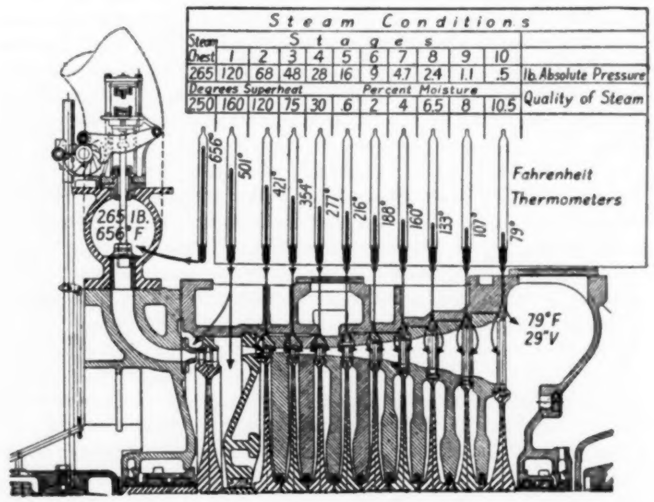


Fig. 3 Cross-Section of 10-Stage Turbine Giving Approximate Steam Conditions in the Stages

TABLE 3 COMPARISON OF QUALITY OF STEAM IN VARIOUS STAGES OF A 10-STAGE TURBINE WHEN STEAM IS INITIALLY DRY AND WHEN THE INITIAL SUPERHEAT IS 250 DEG.

	Stages 1	2	3	4	5	6	7	8	9	10
Dry Initial Steam:										
Per cent of moisture	4.4	6.8	8.15	9.8	11.5	13	14.5	16	17.3	18.7
Initial Superheat 250 Deg.:										
Degrees of superheat	160	120	75	30	..	..	..	..	..	..
Per cent of moisture	..	..	..	..	0.6	2	4	6.5	8	10.5

by extracting steam for heating the feedwater from several stages in the turbine.

Fig. 5 shows approximately the theoretical gain by the use of 1, 2, 3, 5, and 20 heaters. While these curves are calculated for 500 lb. gage pressure, 725 deg. fahr. steam temperature, and 29 in. vacuum, they can be used with comparatively small error for other pressures and temperatures. If the steam is initially dry, the gain would be larger than what is shown but only by a couple of per cent.

The extraction of steam for heating feedwater has also an important gain, in that the more steam is extracted from the turbine before it reaches the condenser, the less steam goes to the condenser, which means a corresponding reduction of heat loss in the condenser.

Reheating

From a glance at the entropy diagram given in Fig. 2 it will be seen that, when adopting pressures of 500 lb. gage and above, there will be excessive moisture in the low-pressure end of the turbine. Reheating is therefore more advisable under those steam conditions than when lower steam pressure is used, although at the lower pressure it is also advisable. But with low initial pressure (250

lb.) the reheating is done at about 50 lb. pressure. The volume of the steam at this pressure is rather large, requiring a large-size reheater not to have too much drop in steam pressure through the reheater. The most economical pressure at which to do the reheating varies, but as a rule, it will be found to be around one-fifth of the initial boiler pressure.

Theoretically, as with initial superheat, the gain is small, being about 3 per cent if the steam is extracted at one-fifth the initial pressure and reheated to the original temperature. The decrease in water rate, however, is about 4 per cent due to reduction of friction losses in turbine. There is of course a slight pressure loss due

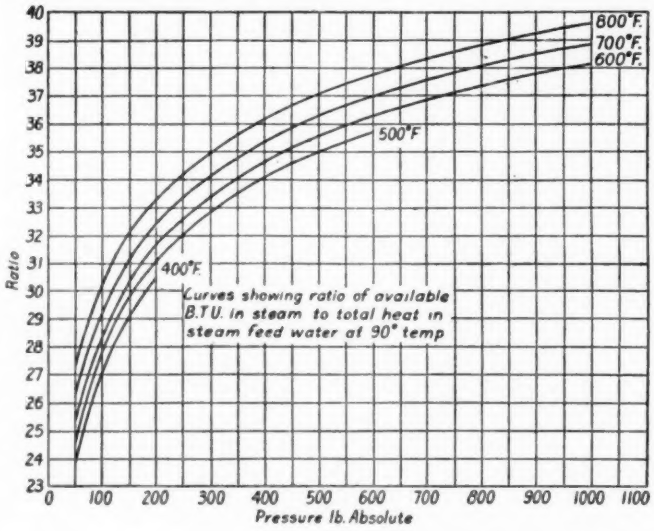


FIG. 4 RATIO OF AVAILABLE B.T.U. TO TOTAL HEAT IN STEAM
(Condensate returned at 90 deg. fahr.)

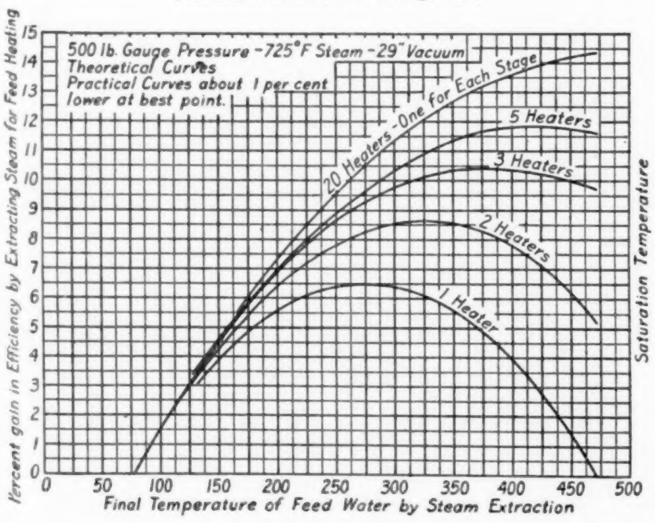


FIG. 5 APPROXIMATE THEORETICAL GAIN BY USE AT EXTRACTION HEATERS

to the piping and the reheater itself, so that the net gain will be about 6 per cent in efficiency.

THE ECONOMIZER

Steam extraction from the turbine for heating the feedwater is so efficient that the use of economizers would seem unnecessary. However, the flue-gas temperature must be kept low in order to keep the efficiency of the boiler plant high. Thus, if economizers are omitted, the waste heat from the gases must be used to preheat the air going to the boilers. Grate manufacturers at the present time prefer to limit the temperature of the air to 300 deg. fahr. or below. However, with oil or powdered coal, high air temperature has proved rather beneficial.

Fig. 6 gives a typical heat balance of a tentative turbine designed for 20,000 kw. and 1800 r.p.m. when operating with 350 lb. gage pressure, 725 deg. fahr. steam temperature, and 29 in. vacuum, with no reheat but with steam extraction to heat the feedwater to 290 deg. fahr. It shows that one kilowatt-hour may be produced with 11,549 B.t.u. from the boilers. For fuel consumption the efficiency of the boilers and power taken by auxiliaries must be

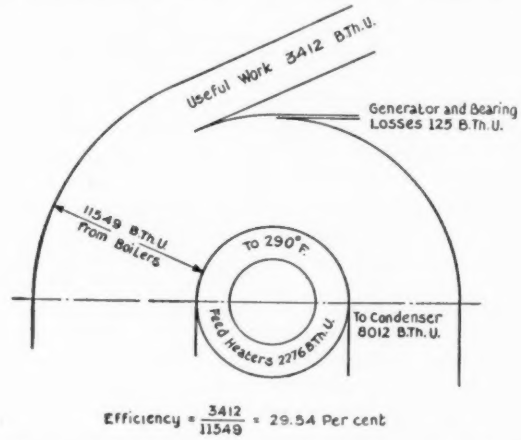


FIG. 6 TYPICAL HEAT BALANCE FOR A STEAM TURBINE. HEAT DISTRIBUTION PER KILOWATT GENERATED
(20,000-kw., 1800-r.p.m. turbine; 350 lb. gage, 725 deg. fahr., 29 in. vacuum; extraction heating, no reheating. For fuel consumption, efficiency of boiler must be allowed for, also auxiliaries.)

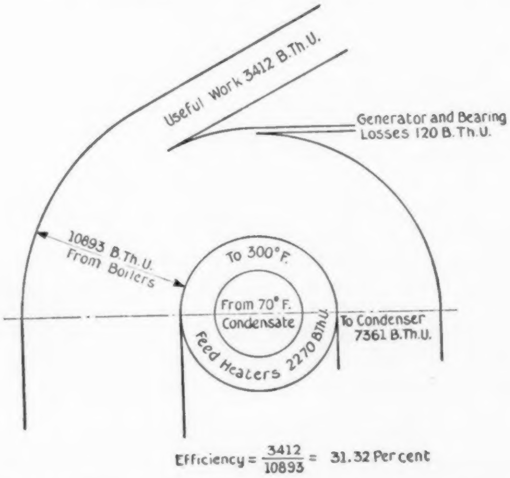


FIG. 7 TYPICAL HEAT BALANCE FOR A STEAM TURBINE. HEAT DISTRIBUTION PER KILOWATT GENERATED; INTERHEATER OUT OF ACTION
(20,000-kw., 1800-r.p.m. turbine; 550 lb. gage, 725 deg. fahr., 29 (30) in. vacuum; extraction heating, no reheating. For fuel consumption, efficiency of boiler must be allowed for also auxiliaries.)

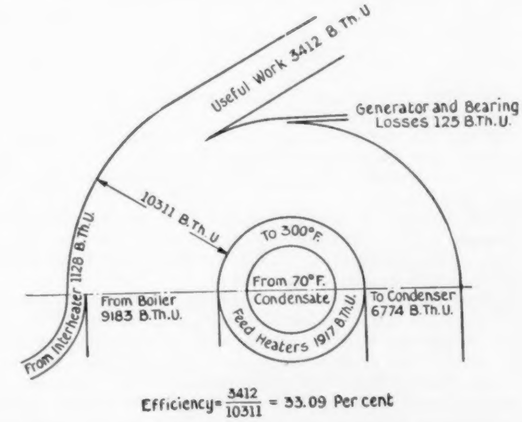


FIG. 8 TYPICAL HEAT BALANCE FOR A STEAM TURBINE. HEAT DISTRIBUTION PER KILOWATT GENERATED; INTERHEATER IN ACTION
(20,000-kw., 1800-r.p.m. turbine; 550 lb. gage, 725 deg. fahr. temp., reheat to 725 deg. at 100 lb., 29 (30) in. vacuum. Extraction heating and reheating at 100 lb. For fuel consumption, boiler and interheater efficiency must be allowed for, also auxiliaries.)

allowed for. Fig. 7 gives the heat balance of the same turbine designed to operate with 550 lb. pressure, 725 deg. fahr. steam temperature, and 29 in. vacuum. Steam is extracted to heat the feed-

water to 300 deg. fahr. With this arrangement a kilowatt-hour may be obtained with 10,893 B.t.u. from the boilers.

Fig. 8 gives the heat balance of the same turbine designed for reheating the steam to 725 deg. at 100 lb. gage pressure, and gives one kilowatt-hour with 10,311 B.t.u. This figure, assuming 80 per cent boiler efficiency and 6 per cent for auxiliaries, would mean 13,700 B.t.u. from the fuel. With oil or powdered coal, where full advantage can be taken of air preheating, the boiler efficiency may reach as high as 90 per cent, in which case the fuel consumption would compare favorably with that of Diesel engines.

II—CALCULATED ANALYSIS OF THE STEAM AND FUEL CONSUMPTION OF A 50,000-HP. TURBINE-ELECTRIC-DRIVE PASSENGER VESSEL

In presenting the following calculated analysis of the steam and fuel consumption of a turbine-electric-drive installation, as proposed for a 50,000-hp. high-speed passenger vessel, it has been the author's endeavor to supply the principles of modern steam-engineering practice as outlined by Mr. Berg to the problem of ship propulsion, and to show in a concrete way the possibilities that exist along economic lines for the practical application of this form of propulsion.

The installation as a whole, including the auxiliary machinery, is treated as a complete mathematical problem. The factors chosen as the basis for the calculations are selected with the greatest care, keeping in mind average values that may be maintained in practice rather than a strict adherence to test results only.

In service a ship may rarely operate at exactly the designed standard conditions. The power and propeller speed become a function of draft, weather conditions, cleanliness of hull, and steering. The steam conditions—pressure, superheat and vacuum—may vary slightly. The auxiliaries may be operated at above or below the standard used as the basis for calculation. Boiler efficiency and the heat value of the fuel may also differ.

Corrective coefficients based on the effect each variable factor has on the fuel consumption have been prepared and applied to the actual operating logs of vessels in service in order that the vessel under consideration may be placed on the same plane as the calculated analysis. Invariably the results have been remarkably close, and the factors chosen proven to be reasonable.

Description of the Equipment

The equipment, which is diagrammatically illustrated in Figs. 9 and 10, consists principally of the following apparatus, for which the data used in the subsequent calculations are likewise given.

Boilers. Eighteen water-tube boilers burning oil, 15 in operation, 3 spare. Heating surface, 5000 sq. ft. Designed for 550 lb. absolute pressure, equipped with air preheaters, and superheaters to deliver steam at 725 deg. fahr. at the turbine throttle. Efficiency, including superheater and air preheater, assumed to be 86 per cent. Oil burned per sq. ft. of heating surface, 0.6 lb. Calculated feedwater temperature, 300 deg. fahr.

Generators. Two 20,000-kw. turbine generators for furnishing power to the main propelling motors and auxiliary motor generators. Steam at throttle 550 lb., 725 deg.; vacuum, 29 in. Calculated water-rate at full power, 8.75 lb. per kw-hr. at generator terminals, excluding excitation. Water rate at motor shafts, including motor losses but excluding excitation, 6.725 lb. per shaft hp-hr.

Synchronous Motors. Two 25,000-shaft-hp. synchronous motors for driving the propeller shafts. Propeller speed, 120 r.p.m.; efficiency, 97 per cent; load on main generator 38,500 kw. The calculations of Table 4 show a fuel consumption of 0.55 lb. per shaft hp-hr.

A.C. Motor-Generator Sets. Two 2000-kw. a.c. motor-generators for furnishing power to the a.c. motor-driven auxiliaries. Estimated load, 1963.5 kw.; efficiency, 86.5 per cent; load on main generator, 2270 kw. Calculated water rate at generator terminals, excluding excitation, 10.1 lb. per kw-hr., when operated from the main generator terminals.

D.C. Motor-Generator Sets. Two 2000-kw. d.c. motor-generator sets for furnishing power to steering gear and excitation current to the main generators, propelling motors, and auxiliary a.c. generator. Estimated load, 465 kw.; efficiency, 84.5 per cent; load on main generator, 550 kw. Calculated water rate at generator terminals, when operated from the main turbine, 10.35 lb. per kw-hr.

Auxiliary Turbines. Each motor-generator set is connected to a turbine by a clutch for independent operation during maneuvering, stand-by, or port operation.

D.C. Generator. One 35-kw. d.c. generator for supplying excitation current to the auxiliary a.c. generator when maneuvering or in port.

Motor-Driven Auxiliaries. Each auxiliary is listed and its power requirements calculated in Tables 6 and 7. Totals are shown to be 1963.5 and 550 kw., respectively, for alternating and direct current.

Air Preheaters. Air heaters of the Howden-Ljungström system have been assumed, giving a stack temperature of about 300 deg. fahr.

Steam Extraction. Steam for heating the feedwater is extracted from the main turbines in sufficient amount to raise the feedwater to a final temperature of 300 deg. fahr. This is accomplished in three separate steps, as follows:

1. Low-pressure heater: steam extracted at 20 lb. absolute pressure to raise temperature to 220 deg. fahr.
2. Intermediate-pressure heater: steam extracted at 40 lb. absolute pressure to raise temperature to 260 deg. fahr.
3. High-pressure heater: steam extracted at 75 lb. absolute pressure to raise temperature to 300 deg. fahr.

In addition to this there is abstracted at 75 lb. absolute pressure and approximately 80 deg. of superheat steam for the following purposes:

Heating the vessel	2500 lb. per hr.
Hot-water service	500 lb. per hr.
Galley, laundry, scullery, etc.	500 lb. per hr.
Heating fuel oil	1700 lb. per hr.
Total	5200 lb. per hr.

The amount of steam extracted at each pressure and the percentage admitted to the main throttle in lieu of that extracted to keep the power output constant is taken up under a subsequent heading Calculation of Multiple-Stage Feedheating System.

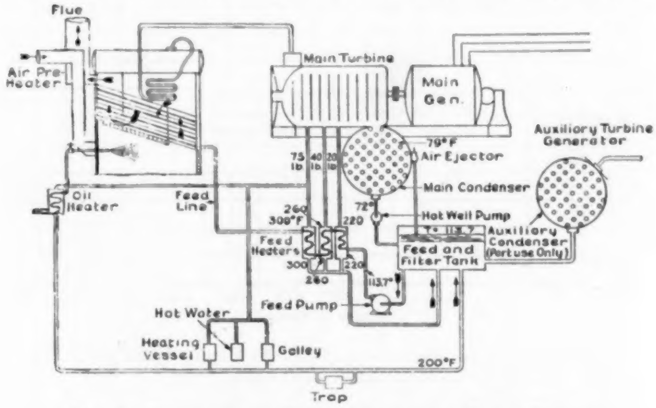


Fig. 9 Diagrammatic Representation of Steam System

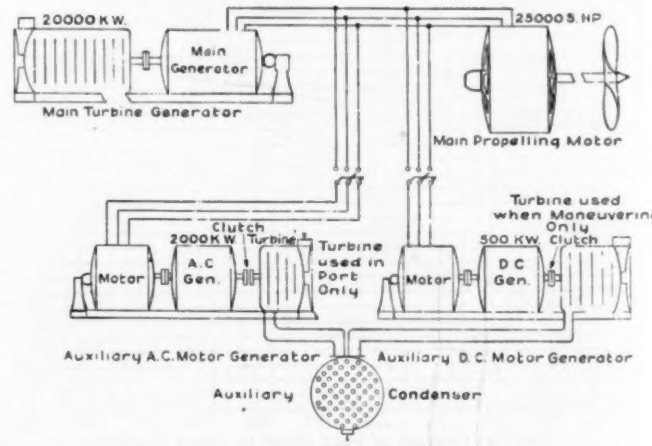


Fig. 10 Diagrammatic Representation of Electrical System

Air Ejectors. Two air ejectors to each condenser, one in continuous operation. Estimated steam consumption each, 1250 lb. per hr., making a total steam consumption of 2500 lb. per hr.

Evaporators. On account of the uncertainty regarding continuity of operation the evaporators are not calculated in the results.

Calculations for Fuel Consumption, Steam Consumption and Auxiliary Power Requirements

Table 4 shows the fuel consumption calculated from the assumed

TABLE 4 FUEL-CONSUMPTION CALCULATIONS

General Conditions:	
Boiler efficiency, per cent	86
Heating value of oil, B.t.u. per lb.	19,000
Total heat of steam, 550 lb. gage, 725 deg. fahr., B.t.u. per lb.	1368.0
Temperature of feedwater, calculated, deg. fahr.	300
Relative evaporation from and at 212 deg., lb.	16,838
Factor of evaporation	1.1335
Actual evaporation per lb. of fuel, lb.	14.855
Pounds of fuel oil per hr.	27.450
Tons of fuel oil per day	294.0
Fuel consumption for all purposes, lb. per shaft hp-hr.	0.55

and other computed data, Table 5 is a summary of the steam-consumption computation, and Tables 6 and 7 give the power requirements of the alternating- and direct-current auxiliaries with the method of calculating the values involved.

TABLE 5 STEAM-CONSUMPTION CALCULATIONS

Main propelling motors, kw.	38,500
Auxiliary a.c. motor generator, kw.	2,270
Auxiliary d.c. motor generator, kw.	550
Total load on main generator, kw.	41,320
Uncorrected steam consumption main turbines (41,320 × 8.75) lb. per kw-hr.	361,550
Correction for steam extraction,[1] lb. per hr.	43,700
Total steam to throttle of main turbines, lb. per hr.	405,250
Air ejectors, consumption, lb. per hr.	2,500
Total steam consumption, lb. per hr.	407,750
Water rate, all purposes, lb. per shaft hp-hr.	8.155

[1] See paragraph, Calculations of Multiple-Stage Feed-Heating System.

TABLE 6 POWER REQUIREMENTS, A.C. MOTOR-DRIVEN AUXILIARIES

Name	Type	No.	Rated b.hp. each	Total b.hp.	Input, kw.	Normal continuous kw.
Feed pumps[1]	Centrifugal	2	300	600	490.0	490.0
Circulating pumps[2]	Centrifugal	2	225	450	375.0	375.0
Condensate pumps[3]	Rotary	2	16	32	28.0	28.0
Forced-draft blowers[4]	——	18	17	256	225.0	225.0
Lubricating-oil pumps[5]	Rotary	2	17	34	30.0	15.0
Oil-cooler circulating[4]	Centrifugal	2	10	20	18.0	9.0
Fuel-oil pumps[6]	Rotary	3	5	15	13.0	9.0
Fire pumps[4]	Centrifugal	2	75	150	125.0	...
Bilge pumps[4]	Centrifugal	2	25	50	44.0	22.0
Fuel-oil transfer[4]	Centrifugal	2	10	20	17.5	5.0
General service[4]	Centrifugal	2	25	50	44.0	22.0
Blowers for motor ventilation[4]	——	4	50	200	165.0	165.0
Lights[4]	——	.	...	...	...	100.0
Bracket fans[4]	——	.	...	...	...	40.0
Electric heaters (staterooms)[4]	——	.	...	...	...	175.0
Ventilating fans[4]	——	.	...	...	...	75.0
Refrigeration[4]	——	.	...	...	...	50.0
Fresh-water pumps[4]	Centrifugal	2	10	20	18.0	9.0
Sanitary pumps[7]	Centrifugal	2	25	50	40.0	20.0
Drinking-water circulating[4]	Centrifugal	1	5	5	4.5	4.5
Miscellaneous elec. appliances[4]	——	.	...	...	...	125.0
Estimated normal load						1,963.5

[1] Discharge pressure, 625 lb.; motor efficiency, 90 per cent; pump efficiency, 50 per cent. Hence

$$\text{kw.} = \frac{407{,}750 \times 625 \times 2.3}{1{,}980{,}000 \times 0.50 \times 0.90} \times 0.746 = 490$$

[2] Ratio of circulation, 70–1; pressure head, 30 ft.; motor efficiency, 90 per cent; pump efficiency, 75 per cent; 320,000 lb. steam to condenser. Hence

$$\text{kw.} = \frac{320{,}000 \times 70 \times 30}{1{,}980{,}000 \times 0.75 \times 0.90} \times 0.746 = 375$$

[3] Total suction and discharge head, 60 ft.; motor efficiency, 85 per cent; pump efficiency, 30 per cent; 320,000 lb. steam to condenser. Hence

$$\text{kw.} = \frac{320{,}000 \times 60}{1{,}980{,}000 \times 0.30 \times 0.85} \times 0.746 = 28$$

[4] Estimated requirements.

[5] Estimated 250 gal. per min.; 60 lb. pressure; pump efficiency, 50 per cent. Hence

$$\text{kw.} = \frac{250 \times 8 \times 60 \times 2.3}{33{,}000 \times 0.50 \times 0.85} \times 0.746 = 15.0$$

[6] Pressure, 150 lb.; capacity, 60 gal. per min.; pump efficiency, 60 per cent. Hence

$$\text{kw.} = \frac{60 \times 8 \times 150 \times 2.3}{33{,}000 \times 0.50 \times 0.85} \times 0.746 = 9$$

[7] Capacity, estimated, 500 gal. per min.; pressure head, 50 lb.

TABLE 7 POWER REQUIREMENTS, D.C. MOTOR-DRIVEN AUXILIARIES

Name	No.	Total b.hp.	Input kw.	Normal continuous kw.
Excitation of main generators and motors	.	...	...	400.0
Excitation of a.c. auxiliary generator	.	...	...	15.0
Steering gear (intermittent)	1	150	130	50.0
Normal continuous load				465.0

Calculation of Multiple-Stage Feed-Heating System

If steam at a pressure of 550 lb. abs., 725 deg. fahr., total heat H = 1368 B.t.u. per lb., is expanded adiabatically to 29.0 in. vacuum, the final total heat will be H_2 = 865 B.t.u. per lb. With a turbine efficiency of 80 per cent, the actual heat at end of expansion will be 1368 — 0.80(1368 — 865) = 965 B.t.u. per lb.

Heat per lb. converted to work, complete expansion
= 402.4 B.t.u.

Heat per lb. converted to work, expanded to 20 lb. abs.
= 226 B.t.u.

Heat per lb. converted to work, expanded to 40 lb. abs.
= 186 B.t.u.

Heat per lb. converted to work, expanded to 75 lb. abs.
= 146 B.t.u.

The amount of steam to admit at throttle in lieu of that extracted at each stage to keep power output constant will be:

High-pressure heater $100 - \left(\frac{146}{402.4}\right) = 64$ per cent

Intermediate-pressure heater $100 - \left(\frac{186}{402.4}\right) = 53.7$ per cent

Low-pressure heater $100 - \left(\frac{226}{402.4}\right) = 43.8$ per cent

The amount of heat per pound available in the extracted steam for heating equals the total heat at the point of extraction minus the heat of the liquid:

High-pressure heater....... (1368 — 146) — 277.4 = 944.6 B.t.u.
Intermediate-pressure heater (1368 — 186) — 236.0 = 946.0 B.t.u.
Low-pressure heater........ (1368 — 226) — 196.1 = 945.9 B.t.u.

As the condensate from the feedwater heaters is returned to the feed and filter tank the heat of the liquid is computed in the calculations covering the inlet temperature to the low-pressure heater.

The amount of steam necessary to extract at 75 lb. pressure to raise the temperature from 260 to 300 deg. fahr. is 40 ÷ 945 = 0.0425; to raise intermediate-pressure heater from 220 to 260 deg. fahr. is 40 ÷ 946 = 0.0425; and to raise low-pressure heater from the temperature at the feed and filter tank (113.7 deg. fahr.) to 220 deg. fahr. is 106.3 ÷ 945 = 0.1125.

The quantities extracted and admitted (in pounds) are as follows:

Extract at 75 lb. abs. pressure:	
For feed-heating purposes (407,750 × 0.0425)	17,300
For heating vessel, heating oil, etc.	5,200
Amount extracted	22,500
Per cent to admit at throttle (64)	0.64
Amount admitted in lieu of that extracted	14,400
Extract at 40 lb. abs. pressure:	
For feed-heating purposes (407,750 × 0.0425)	17,300
Per cent to admit at throttle (53.7)	0.537
Amount admitted in lieu of that extracted	9,300
Extract at 20 lb. abs. pressure:	
For feed-heating purposes (407,750 × 0.1125)	45,700
Per cent to admit at throttle (43.8)	0.438
Amount admitted in lieu thereof	20,000
Total amount extracted (22,500 + 17,300 + 45,700)	85,500
Total amount admitted (14,400 + 9,300 + 20,000)	43,700

It is interesting to note that the total reduction in power due to extracting 85,500 lb. of steam at the various pressures is approximately [illegible]000 kw. This power is regained by admitting 43,700 lb. of live steam as shown above.

Heat-Balance Calculations

The steam distribution and heat balance based upon the fundamental data are given in Tables 8 and 9.

TABLE 8 STEAM DISTRIBUTION

	Lb. per hr.	Per cent
Main turbines (41,320 kw. × 8.75)	361,550	...
Steam extracted for feed heating, heating vessel, etc.	85,500	...
Balance	276,050	
Amount admitted in lieu of that extracted	43,700	...
Net amount to condenser	319,750	78.35
Air ejectors (to feed and filter tank)	2,500	0.62
Extracted steam used for feedwater heating:		
High-pressure heater	17,300	4.25
Intermediate-pressure heater	17,300	4.25
Low-pressure heater	45,700	11.25
Returned to feed and filter tank	80,300	
Extracted steam used for heating:		
Oil heaters	1,700	...
Heating vessel, galley, etc.	3,500	...
Total	5,200	
Estimated leakage losses	3,500	...
Returned to feed tank	1,700	0.40
Make-up feedwater	3,500	0.88
Totals	407,750	100.00

TABLE 9 HEAT BALANCE

Source	Lb. per hr.	Temp. deg. fahr.	B.t.u. per lb.	Per cent wt.	B.t.u.
Condensate from condensers	319,750	72	40	78.35	3134.0
Condensate from feed heaters:					
High-pressure feed heaters	17,300	300	268	4.25	1139.0
Intermediate-pressure feed heaters	17,300	260	228	4.25	969.0
Low-pressure feed heaters	45,700	220	188	11.25	2115.0
Air ejectors	2,500	212	1150	0.62	713.0
Condensate from oil heaters	1,700	200	168	0.40	67.0
Make-up feedwater	3,500	70	38	0.88	33.5
Total	407,750			100.00	8170.5
B.t.u. per lb.					81.7
Temperature, deg. fahr.					113.7

Temperature Rise at Feed Heaters and Final Temperature of Feedwater

Final temperature at low-pressure heater =

$$113.7 + \left(\frac{45{,}700 \times 945}{407{,}750}\right) = 220.0 \text{ deg. fahr.}$$

Final temperature at intermediate-pressure heater =

$$220.0 + \left(\frac{17{,}300 \times 945}{407{,}750}\right) = 260.0 \text{ deg. fahr.}$$

Final temperature at high-pressure heater =

$$260.0 + \left(\frac{17{,}300 \times 945}{407{,}750}\right) = 300.0 \text{ deg. fahr.}$$

Conclusions

The application of the principles involved in the preceding analysis are not new or untried, although they may seem revolutionary when applied to ship-propulsion problems. The underlying reason for adopting high-pressure, high-temperature steam is the large gain in available energy with an unappreciable expenditure of increased heat. Furthermore, the frictional losses in the turbine are decreased.

The steam-extraction method for heating the feedwater to a high temperature has been adopted for the following reasons:

1 It permits of better turbine design
2 It reduces to a minimum the amount of heat lost in the condenser
3 It returns the maximum amount of latent heat to the boilers, thereby increasing the evaporation per pound of fuel and reducing the fuel consumption.

In the foregoing analysis it will be noted that should the main turbines be operated without steam extraction the quantity of steam entering the condenser would be 361,550 lb. per hr. Due to the extraction method the total quantity entering the condenser is reduced to 319,750 lb. per hr. The latent heat of this difference of 41,800 lb. is returned to the boilers, thereby saving in fuel 2420 lb. per hr. or 26 tons per day. Another distinct gain is the smaller condensing equipment required and the reduced power of the condenser auxiliaries.

The complete electrification of the auxiliary equipment was adopted for the reason that by this method it was possible to take advantage of the low water rate of the main propelling equipment and apply it direct to various small powers without an appreciable loss in its transmission.

The motor-generator method of producing this auxiliary power was adopted for the reason that the method lends itself to change-over duty, that is, from port to sea operation, without complication.

In the advancement of the science of steam engineering as applied to ship propulsion it appears quite reasonable to believe that the various measures as applied in the foregoing analysis must on account of their economic importance be seriously considered in future installations.

Power Consumption in Air-Liquefaction Plants

A kilogram of liquid air may be considered from the point of view of the heat—and in this case the cold—that can be abstracted from it, and within the temperature range of +15 deg. cent. (59 deg. fahr.) to —190 deg. cent. (—310 deg. fahr.) there may be abstracted from it 98 large calories. This figure represents the optimum heat value and may also be considered as the limiting value in the manufacture of liquid air, as it is the amount which would be ideally sufficient to produce one kilogram of liquid air. The actual amounts are, of course, very much greater. Dr. R. Linde, writing in *Zeitschrift des Vereines deutscher Ingenieure*, 1921, no. 52, states that the power consumption in producing one kilogram of liquid air is 2180 cal. (= 3.45 hp-hr.) when the air is exhausted at 200 lb. pressure into the atmosphere, and 1230 cal. (= 1.95 hp-hr.) when the air is employed in accordance with the principle of double expansion. These figures were obtained in actual practice and apply to the production of liquid air but not of liquid oxygen, in which case very much higher figures become necessary.

Better results than this are obtained while producing liquid air with the assistance of adiabatic expansion and under conditions of delivery of external work. It is claimed that the Heylandt expansion machine produces an amount of liquid air out of a given weight of ordinary air that has not been surpassed by other processes. In this process a part of the high-pressure air required is employed in the expansion-machine head of the air-liquefying apparatus and is only then permitted to enter the latter, while another part of the air is admitted directly into the air-liquefying apparatus through the expansion valve. To control this separation of air the high-pressure piping after it passes the air-drying battery is provided with the bypass leading to an admission valve of its own. The high-pressure air enters the admission valve of the cylinder with the temperature of the cooling water and leaves it through the outlet valve with a temperature of —140 to —150 deg. cent. (—220 to —238 deg. fahr.). The cold air coming from the expansion machine is delivered at a certain point to the counter-current heat exchanger of the air-liquefaction machine, where it passes through a special pipe spiral in counterflow to the gases coming from the air-liquefaction apparatus, leaving the machine at its lower end.

It is claimed that to produce one kilogram of liquid oxygen of a purity of 88 per cent in the expansion machine only 1.26 kw-hr. (equal to 1.71 hp-hr.) is needed.

The original article gives data of tests of output and power consumption of expansion air-liquefaction machines at several installations in Germany. In one of these 321 kw. were read off the meter in 12 hr., the production of liquid oxygen of an average purity of 85 per cent being (including evaporation losses) 255.37 kg. In another test the consumption of power per kilogram of liquid oxygen of an average purity of 90 per cent was found to be 1.38 kw-hr. (equal to 1.88 hp-hr.).

It is pointed out, however, that the above figures apply to plants having a capacity of 15 kg. of liquid air per hour and would not apply to much smaller plants. (C. P. W. Heylandt in *Zeitschrfit für Sauerstoff-und Stickstoff-Industrie*, vol. 16, no. 6, June, 1924, pp. 41–43.)

Drawing Small Tubes of Precious Metals

Description of methods of drawing small tubes of platinum and gold where the value of materials is so great that extreme care must be used in avoiding waste, is given by Jack Williams in the *American Machinist*, for August 21, 1924.

The process is of the cupping type and, with the exception of the first operation, is done by means of hand-operated tools. The entire drawing is done in three steps. First is the blanking and cupping operation, conducted in a small power press of standard make. This is followed by redrawing done on a Greenerd arbor press. In this the original cup is reduced to a tube about 1/4 in. in diameter by 6 or 8 in. long. Further reduction is accomplished in a horizontal drawing machine having a screw-operated slide moving in carefully fitted ways over the length of its upper surface, a square-thread screw of large cross-section to move it, and a driving shaft fitted with one of a pair of bevel gears, the mate to which is keyed to the screw. The machine works on the push-through principle.

Because of the intrinsic value of the material, extreme care must be exercised in every operation. Reduction in diameter between successive draws is small, amounting to but a few thousandths in many cases, and the tubes must be annealed frequently. Though every particle of scrap is scrupulously looked after, there is a definite loss in every remelting, and therefore the making of scrap must be avoided to the utmost degree. The amount of reduction at each draw and the frequency of annealing depend to a large extent upon the exact nature of the alloy.

One factor that troubles the brass-tube mill does not bother the worker in precious metals to any extent—platinum and fine gold do not oxidize by heat. A piece of platinum of the brightness of polished silver may be raised to a dazzling white heat and when cooled will be as clean and bright as it was before heating.

Mathematical Theory of Dynamic Stresses in Rotating Gear Pinions

By PAUL HEYMANS,[1] CAMBRIDGE, MASS.

The theoretical study of the dynamic stresses in rotating gear pinions presented in this paper has been developed in the course of the investigation by the photoelastic method of the stresses in gear pinions undertaken by the Research Laboratories and the Railway Motor Engineering Department of the General Electric Co., Schenectady, N. Y., and conducted at the Massachusetts Institute of Technology. Further photoelastic investigations will be necessary to verify the validity of the theoretical derivations and to embody them into quantitative relations of direct use in practice.

THERE appears to be a tendency to attribute the existence of the dynamic stresses in rotating gear pinions solely to the irregularities of the teeth, and to assert that the stresses with perfectly formed and spaced teeth under a dynamic torque, and the same torque statically applied, are the same.

A mathematical theory of the stresses in rotating gear pinions is presented in this paper. It is shown that in all disturbed elastic media a force applied cyclically along any closed contour results in oscillatory deformations and corresponding dynamic stresses. Likewise in rotating gear pinions a torque acting on perfectly formed and spaced gear teeth sets up similar dynamic stresses. Variations in the torque and irregularities in the teeth only result in the change of the amplitude or in the addition of one or several harmonic terms for the disturbing force.

The frequencies of the free or transient dynamic stresses which are set up depend upon the geometrical configuration and the elastic constants of the system, whereas the frequencies of the forced components, which are the only dynamic stresses existing in the steady state, are the frequencies of the one or several harmonic components of the impressed force. The maximum deformation and the maximum stress of the transient components of the dynamic stresses depend on the geometrical configuration of the system, its density, and its elastic constants. The maximum of the steady-state components depends on the frequencies of the harmonic components of the impressed force and the free or natural frequencies of the system. It follows that the maximum stress in any system of rotating pinions depends upon Young's modulus of elasticity,[2] the internal friction, and the relation between the frequencies of free oscillation and the frequencies of the impressed force.

Formulas expressing the relations of the allowable load on spur gear teeth—and hence the maximum stress—to the velocities which fail to take into account all or part of these fundamental variables which determine the maximum stress, appear to be, in the light of the present theory, incomplete in their fundamentals.

Static and Dynamic Stresses in Discontinuous Media of Independent Mass Points

Consider an ideal disk (Fig. 1) rigidly clamped at its center. Assume the disk to be formed by *independent* mass particles obeying individually Hooke's law of linear proportionality between the elastic force and the displacement from their position in the unstressed state.

1 Let a tangential force F_1 be applied at point (1).

The tangential force at (1) statically applied to the disk will result in a static stress distribution in accordance with the theory of torsion.

If the force F_1 is removed, d'Alembert's equation of dynamic equilibrium between the inertia force and the elastic force gives as the differential equation of motion for any one of the points of the disk

$$I\frac{d^2\theta}{dt^2} = -G\frac{\theta}{l}\dots\dots\dots\dots\dots\dots\dots [1]$$

where $\frac{k}{l}\theta$ is the restoring couple called into play by the elastic force θ the angle of displacement, G the modulus of torque, l the longitudinal dimension of the disk, and I the moment of inertia about the axis of rotation.

The general solution of Equation [1] gives the following kinetic equation of motion:

$$\theta = A\cos\sqrt{\frac{G}{Il}}\,t + B\sin\sqrt{\frac{G}{Il}}\,t\dots\dots\dots\dots [2]$$

where A and B are two arbitrary constants determined by the conditions of the motion at any given time at the point under consideration.

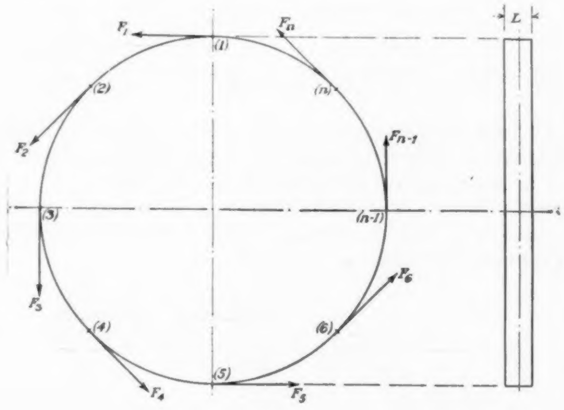


Fig. 1

It results from Equation [2] that the different points of the disk will perform torsional oscillations around its longitudinal axis.

The period of the simple harmonic motion is

$$T = 2\pi\sqrt{\frac{Il}{G}}$$

The oscillation is solely due to the action of the elastic forces once the system has been initially disturbed by the external force F_1. Such oscillations are called "free" oscillations.

2 Let the tangential force F_1 be replaced by a periodic disturbing force $f(t)$ applied at the same point (1). Such a periodic disturbing force can be resolved, at least during its time of application, into the terms of an absolutely convergent Fourier's series such as follows:

$$f(t) = A_0 + A_1\cos p_1t + A_2\cos p_2t + \dots\dots$$
$$+ B_1\sin p_1t + B_2\sin p_2t + \dots\dots$$

If the series reduces to the term

$$f(t) = A\cos pt$$

the differential equation for this "forced" motion becomes

$$I\frac{d^2\theta}{dt^2} + \frac{G}{l}\theta = A\cos pt\dots\dots\dots\dots\dots\dots [3]$$

The general solution of this equation is

$$\theta = \frac{A/I}{p_0^2 - p^2}\cos pt + C\cos p_0t + D\sin p_0t\dots\dots\dots [4]$$

[1] Asst. Prof., Massachusetts Institute of Technology. Assoc-Mem. A.S.M.E.

[2] There exist also oscillatory deformations in a direction normal to the plane of the impressed force, but they do not have to be considered in the stress problem. There are only two principal stresses in the plane of the gear, notwithstanding the existence of three principal dilatations. Poisson's ratio does therefore not come into consideration.

Presented at the Spring Meeting, Cleveland, Ohio, May 26 to 29, 1924, of The American Society of Mechanical Engineers, 29 West 39th St., New York.

where p_0 is the circular frequency $\sqrt{\frac{G}{Il}}$ of the free oscillating system, whereas p is the circular frequency of the disturbing force.

If the function $f(t)$ expressing the periodic disturbing force resolves into m harmonic terms, the kinetic equation of motion for any point becomes

$$\theta = C \cos p_0 t + D \sin p_0 t + \sum_{\nu}^{1,2..m} \frac{A_\nu/I}{p_0^2 - p_\nu^2} \cos p_\nu t \ldots [5]$$

where $\nu = 1, 2, \ldots m$.

If frictional forces, proportional to the velocity, are introduced into Equation [3], the differential equation of motion becomes

$$I \frac{d^2\theta}{dt^2} + kr \frac{d\theta}{dt} + \frac{G}{l} \theta = A \cos pt \ldots\ldots\ldots\ldots [6]$$

and the solution of this equation is

$$\theta = e^{\frac{-kr}{2I} t} \left[C \cos p_0 + D \sin p_0 t \right] + \frac{A \cos (pt - \psi)}{I\rho} \ldots [7]$$

where

$$\psi = \tan^{-1} \frac{\frac{kp}{I}}{p_0^2 - p^2} \text{ and } \rho = \sqrt{(p_0^2 - p^2)^2 + \frac{k^2r^2p^2}{I^2}}$$

The first term of the second member of Equation [7] represents the transient or free components of the oscillation. These components decrease exponentially with increasing time.

The second term of the second member of Equation [7] represents the oscillations in the steady state. These stationary oscillations θ_1 are expressed as follows:

$$\theta_1 = \frac{A \cos (pt - \psi)}{I\rho} = \frac{(A/I) \cos (pt - \psi)}{\sqrt{(p_0^2 - p^2)^2 + \frac{k^2r^2p^2}{I^2}}} \ldots\ldots [8]$$

Equation [8] readily shows that in the steady state the deformations remain oscillatory with a circular frequency p equal to the circular frequency of the periodic force, and with a constant amplitude

$$h = \frac{A/I}{\sqrt{(p_0^2 - p^2)^2 + \frac{k^2r^2p^2}{I^2}}}$$

It also results from Equation [8] that with respect to the undamped forced oscillations, the damped forced oscillations have undergone a relative retardation in phase ψ.

If m harmonic terms enter into the disturbing force $f(t)$, Equation [8] becomes

$$\theta_1 = \sum_{\nu}^{1,2\ldots m} \frac{A_\nu/I \cos (p_\nu t - \psi_\nu)}{(p_0^2 - p_\nu^2)^2 + \frac{k^2r^2p^2}{I^2}} \ldots\ldots\ldots\ldots [8a]$$

3 Let the tangential forces F_1, F_2, $\ldots F_n$ act successively at their respective points of application. Let them act at regular intervals of time T, although any periodicity for each of them could be readily considered.

Each of the F_n forces, acting with a circular frequency $1/nT$, will set up oscillatory deformations as expressed by Equations [2], [4], [5], [7], [8], and [8a].

By virtue of the principle of superposition, the resultant deformation at any time will be the sum of the individual deformations due to each of the forces acting alone. If any of the deformation components become infinite, the resultant deformation becomes infinite.

The cyclical periodic applications of the n forces will result, in the steady state, in an oscillation of the type embodied in Equation [8a], except that the summation will extend to all the forces F_1, F_2, $\ldots F_n$ acting with a frequency $1/nT$. It can be expressed as follows:

$$\theta_1 = \sum_{\lambda}^{1,2\ldots m} \sum_{\nu}^{1,2\ldots m} \frac{(A_{\nu\lambda}/I) \cos (p_{\nu\lambda} t - \psi_{\nu\lambda})}{\sqrt{(p_0^2 - p_{\nu\lambda}^2)^2 + \frac{k^2r^2p_{\nu\lambda}^2}{I^2}}}$$

This represents the case of rotating gear pinions with perfectly formed and spaced teeth, where the constant tangential force acts cyclically on successive teeth in the manner described. A few characteristics of these oscillatory deformations are:

1 With no frictional forces, if $p_0 = p_{\nu\lambda}$, the amplitude becomes infinite. This case of resonance between the natural frequency p_0 of free oscillations of the system and the frequency of one of the disturbing forces, leads, in a frictionless system (also in a massless system where $I = \Sigma mr^2 = 0$), to an infinite strain. It results directly from the stress-strain relation that whenever oscillatory deformations exist, corresponding oscillatory stresses are set up. The strain and stress diagrams vs. time at any given point, excepting the points on the axis of rotation, are therefore qualitatively represented by Fig. 2.

2 With damping frictional forces the amplitude still depends upon the frequencies p_0 and $p_{\nu\lambda}$. However, if $p_{\nu\lambda}$ is equal to p_0

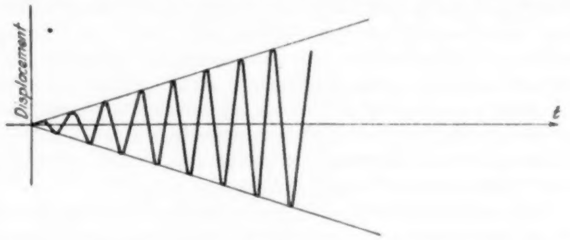


FIG. 2

the amplitude does not become infinite. The maximum will correspond to the value of $p_{\nu\lambda}$ for which

$$\rho = \sqrt{(p_0^2 - p_{\nu\lambda}^2)^2 + \frac{k^2r^2p_{\nu\lambda}^2}{I^2}}$$

is a minimum.

This value is obtained by equating to zero the derivative of ρ with respect to $p_{\nu\lambda}$, or

$$\frac{1}{2} \frac{d\rho}{dp_{\nu\lambda}} = \frac{-2(p_0^2 - p_{\nu\lambda}^2)p_{\nu\lambda} + \frac{k^2r^2p_{\nu\lambda}^2}{I^2}}{\sqrt{(p_0^2 - p_{\nu\lambda}^2)^2 + \frac{k^2r^2p_{\nu\lambda}^2}{I^2}}}$$

whence

$$p_{\nu\lambda}^2 = p_0^2 - \frac{k^2r^2}{2I^2}$$

$$(\theta_1)_{\max} = \frac{A_{\nu\lambda} \cos \left[\left(p_0^2 - \frac{k^2r^2}{2I^2} \right) t - \psi_{\nu\lambda} \right]}{kr \sqrt{p_0^2 - \frac{k^2r^2}{4I^2}}}$$

and

$$(h_1)_{\max} = \frac{A_{\nu\lambda}}{kr \sqrt{p_0^2 - \frac{k^2r^2}{4I^2}}}$$

Dynamic Stresses in Pseudo-Continuous Media

A—Free Undamped Motion in Pseudo-Continuous Media. The discussion has so far assumed that each point of the system is free to vibrate irrespective of the state of motion of the neighboring points. Each particle of the disk is, in fact, elastically connected to the next one. Let us express this property by calling the medium a pseudo-continuous medium.

This case can be approached by the more general Lagrangian

equations of motion. Let us consider (Fig. 3) any two points m_1 and m_2 upon which are acting the usual elastic forces (1) and (2) and also the mutual elastic connection (12). Their position of equilibrium in the unstressed state being $\psi = 0$, Fig. 3 represents their positions at a given time.

The partial potential energies of this system are

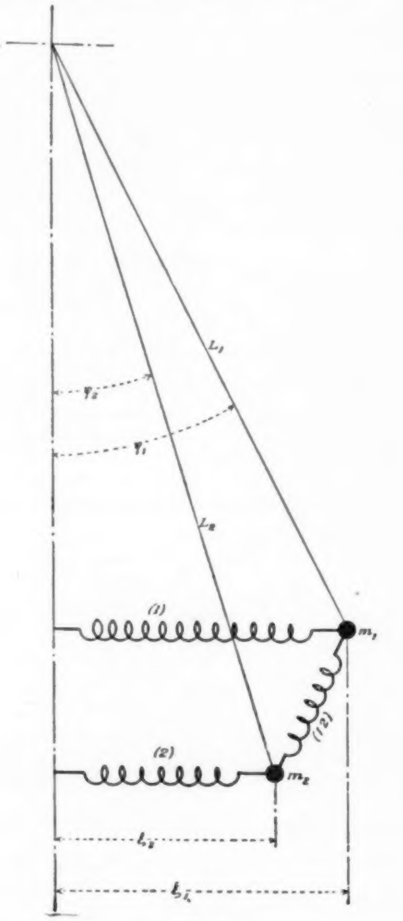


FIG. 3

$$\phi_{12} = \frac{E_1}{2}(\xi_2 - \xi_1)^2$$

$$\phi_1 = \frac{E_2}{2}\xi_1^2$$

$$\phi_2 = \frac{E_2}{2}\xi_2^2$$

where ξ_1 and ξ_2 are the linear displacements and E_1 and E_2 elastic constants.

The total potential energy of the system is

$$\phi = \frac{E_1}{2}(\xi_2 - \xi_1)^2 + \frac{E_2}{2}(\xi_2^2 + \xi_1^2)$$

The total kinetic energy T is similarly obtained by summation of the partial kinetic energies and is equal to

$$T = \frac{m_1}{2}\left(\frac{d\xi_1}{dt}\right)^2 + \frac{m_2}{2}\left(\frac{d\xi_2}{dt}\right)^2$$

The equations of motion in the Lagrangian form here are

$$\frac{d}{dt}\left[\frac{\partial T}{\partial\left(\frac{d\xi_\nu}{dt}\right)}\right] + \frac{\partial\phi}{\partial\xi_\nu} = 0 \qquad [9]$$

where T and ϕ are the kinetic and potential energies and ξ_ν the ν independent coördinates necessary to define fully the position of the system.

Making the following substitution of variables:

$$\xi_1 = l_1\psi_1$$

$$\xi_2 = l_2\psi_2$$

we obtain

$$\phi = \frac{E_1}{2}(l_2\psi_2 - l_1\psi_1)^2 + \frac{E_2}{2}l_1\psi_1^2 + \frac{E_2}{2}l_2^2\psi_2^2$$

$$= \frac{\psi_1^2}{2}(E_1l_1^2 + E_2l_1^2) + \frac{\psi_2^2}{2}\left(E_1l_2^2 + E_2l_2^2\right) - E_1l_1l_2\psi_1\psi_2$$

$$\frac{\partial\phi}{\partial\psi_1} = (E_1l_1^2 + E_2l_1^2)\,\psi_1 - E_1l_1l_2\psi_2$$

$$\frac{\partial\phi}{\partial\psi_2} = (E_1l_2^2 + E_2l_2^2)\,\psi_2 - E_1l_1l_2\psi_1$$

Also

$$T = \frac{m_1}{2}l_1^2\left(\frac{d\psi_1}{dt}\right)^2 + \frac{m_2}{2}l_2^2\left(\frac{d\psi^2}{dt}\right)^2$$

If $\quad \frac{d\psi_1}{dt} = \chi_1$

and $\quad \frac{d\psi_2}{dt} = \chi_2$

then

$$T = \frac{m_1}{2}l_1^2\chi_1^2 + \frac{m_2}{2}l_2^2\chi_2^2$$

$$\frac{\partial T}{\partial\chi_1} = m_1l_1^2\chi_1 \qquad \frac{\partial T}{\partial\chi_2} = m_2^2l_2^2\chi_2$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial\chi_1}\right) = m_1l_1^2\frac{d^2\psi_1}{dt^2};\quad \frac{d}{dt}\left(\frac{\partial T}{\partial\chi_2}\right) = m_2l_2^2\frac{d^2\psi_2}{dt^2}$$

Introducing these values in Equation [9], the following differential equations of motion are obtained.

$$\left.\begin{aligned} m_1l^2_1\frac{d^2\psi_1}{dt^2} + (E_1l_1^2 + E_2l_1^2)\psi_1 - E_1l_1l_2\psi_2 &= 0 \\ m_2l_2^2\frac{d^2\psi_2}{dt^2} + (E_1l_2^2 + E_2l_2^2)\psi_2 - E_1l_1l_2\psi_1 &= 0 \end{aligned}\right\} \ldots [10]$$

The solutions of these equations lead to the kinetic equations of motion $\psi_1 = f_1(t)$ and $\psi_2 = f_2(t)$ of the two particles m_1 and m_2 allowed to vibrate freely under the sole action of elastic forces proportional to the displacement.

The solution of these two linear differential equations of the second order is obtained by writing the solution in the form

$$\left.\begin{aligned} \psi_1 &= A_1e^{ipt} \\ \psi_2 &= A_2e^{ipt} \end{aligned}\right\} \ldots\ldots\ldots\ldots [11]$$

where A_1, A_2 and p are three constants which must be determined.

Differentiating [11] twice with respect to t and substituting in [10] for ψ_1, ψ_2, $\frac{d^2\psi_1}{dt^2}$, and $\frac{d^2\psi_2}{dt^2}$ the values obtained, Equations [10] become

$$\left.\begin{aligned} A_1[E_1l_1^2 + E_2l_1^2 - m_1l_1^2p^2] + A_2[-E_1l_1l_2] &= 0 \\ A_1[-E_1l_1l_2] + A_2[E_1l_2^2 + E_2l_2^2 - m_2l_2^2p^2] &= 0 \end{aligned}\right\} \ldots [12]$$

Neglecting the trivial solution $A_1 = A_2 = 0$, these two linear equations will be generally satisfied by the condition that the determinant formed with the coefficients of A_1 and A_2 is equal to zero. Whence

$$\begin{vmatrix} (E_1l_1^2 + E_2l_1^2 - m_1l^2_1p^2) & , \quad -E_1l_1l_1 \\ -E_1l_1l_2, & , \quad (E_1l_2^2 + E_2l_2^2 - m_2l_2^2p^2) \end{vmatrix} = 0$$

and

$$Ap^4 - Bp^2 + C = 0 \qquad [13]$$

where

$$A = m_1 m_2 l_1^2 l_2^2$$
$$B = l_1^2 l_2^2[(m_1 + m_2)(E_1 + E_2)]$$
$$C = l_1^2 l_2^2(E_2^2 + 2E_1E_2)$$

The roots of Equation [13] being

$$\left.\begin{aligned} p_1^2 &= \frac{B + \sqrt{B^2 - 4AC}}{2A} \\ p_2^2 &= \frac{B - \sqrt{B^2 - 4AC}}{2A} \end{aligned}\right\} \qquad [14]$$

where p_1 and p_2 are the circular frequencies of m_1 and m_2. If the symmetric case, in which

$$m_1 = m_2 = m$$
$$l_1 = l_2 = l$$
$$E_1 = E_2 = E$$

is considered, the frequencies become

$$p_1^2 = \frac{3E}{m}$$

$$p_2^2 = \frac{E}{m}$$

and

$$\left.\begin{aligned} \psi_1 &= A_1 \cos\sqrt{\frac{3E}{m}}\, t \\ \psi_2 &= A_2 \cos\sqrt{\frac{E}{m}}\, t \end{aligned}\right\} \qquad [15]$$

For any positive value for m_1 and m_2, p_1 and p_2 will not be equal. It is thereby seen that the different points of the pseudo-continuous medium are not oscillating insynchronism.

B—Forced Damped Oscillations in Pseudo-Continuous Media. Equations [15] are the solutions for a free undamped system. Let us now consider this same system under the influence of a periodic force—which may be expressed as a harmonic function of the time and consequently as the real part of an imaginary exponential function of the time—and under the influence of elastic and frictional forces respectively proportional to the displacement and to the velocity.

The motion of the system is then given by the two following differential equations for which the Heaviside operational method[1] offers a solution.

$$\left.\begin{aligned} m_1 l_1^2 \frac{d^2\psi_1}{dt^2} + (E_1 l_1^2 + E_2 l_1^2)\psi_1 + k l_1 \frac{d\psi_1}{dt} - E_1 l_1 l_2 \psi_2 &= f(t) \\ m_2 l_2^2 \frac{d^2\psi_2}{dt^2} + (E_1 l_2^2 + E_2 l_2^2)\psi_2 + k l_2 \frac{d\psi_2}{dt} - E_1 l_1 l_2 \psi_1 &= 0 \end{aligned}\right\} \qquad [16]$$

Operationally, Equations [16] may be written in the form:

$$\left.\begin{aligned} (a_{11}p^2 + b_{11}p + c_{11})\psi_1 + (a_{12}p^2 + b_{12}p + c_{12})\psi_2 &= f(t) \\ (a_{21}p + b_{21}p + c_{21})\psi_1 + (a_{22}p^2 + b_{22}p + c_{22})\psi_2 &= 0 \end{aligned}\right\} \qquad [17]$$

where p^n is the operator $\frac{d^n}{dt^n}$ which, when applied to an operand ψ, yields the nth derivative of ψ with respect to the parameter t, n being a real integer.

In general the disturbing force will be expressed by an absolutely convergent series of harmonic terms. If more than one harmonic term is considered, the solution of Equations [17] has to be written for each harmonic force component separately and the resultant motion—by virtue of the principle of superposition, or of the principle of independent action of forces—is obtained as before by the addition of the individual displacements due to each force component.

The solution of the primitive Equations [16] will again consist of two parts, the forced components of oscillation and the free components. As before, the forced components are obtained by the particular solutions of the equations and their frequency will be the frequency of the disturbing force.

These particular solutions are obtained in the familiar way by solving the above system of linear Equations [17]. Denoting them by y_1 and y_2 we have:

$$y_1 = \frac{\begin{vmatrix} Ae^{ipt} & , & a_{12}p^2 + b_{12}p + c_{12} \\ 0 & , & a_{22}p^2 + b_{22}p + c_{22} \end{vmatrix}}{\begin{vmatrix} a_{11}p^2 + b_{11}p + c_{11} & , & a_{12}p^2 + b_{12}p + c_{12} \\ a_{21}p^2 + b_{21}p + c_{21} & , & a_{22}p^2 + b_{22}p + c_{22} \end{vmatrix}} = \frac{\Delta_{22}(p)}{\Delta(p)} Ae^{ipt} \qquad [18]$$

and likewise

$$y_2 = \frac{\Delta_{21}(p)}{\Delta(p)} Ae^{ipt}$$

where

$$\begin{aligned} a_{11} &= m_1 l_1^2 & a_{22} &= m_2 l_2^2 \\ b_{11} &= k l_1 & b_{22} &= k l_2 \\ c_{11} &= E_1 l_1^2 + E_2 l_1^2 & c_{22} &= E_1 l_2^2 + E_2 l_2^2 \\ c_{12} &= -E_1 l_1 l_2 & c_{21} &= -E_1 l_1 l_2 \\ a_{12} &= b_{12} = a_{21} = b_{21} = 0 \end{aligned}$$

The free components z_1 and z_2, given by the solutions of the *reduced* Equations [17], are

$$\left.\begin{aligned} z_1 &= \sum_k B_{1k} e^{ip_k t} \\ z_1 &= \sum_k B_{2k} e^{ip_k t} \end{aligned}\right\} \qquad [19]$$

where p_k is a root of the determinantal equation $\Delta(p) = 0$ and the summation for z_1 and z_2 is extended over the degrees of freedom of each particle.

The complete solutions of Equations [16] are therefore

$$\left.\begin{aligned} \psi_1 &= y_1 + z_1 = \frac{\Delta_{22}(p)}{\Delta(p)} Ae^{ipt} + \sum_k B_{1k} e^{ip_k t} \\ \psi_2 &= y_2 + z_2 = \frac{\Delta_{21}(p)}{\Delta(p)} Ae^{ipt} + \sum_k B_{2k} e^{ip_k t} \end{aligned}\right\} \qquad [20]$$

Carrying solutions [20] further for the symmetrical conditions where

$$a_{11} = a_{22} = ml^2$$
$$b_{11} = b_{22} = kl$$
$$c_{11} = c_{22} = 2El^2$$
$$c_{12} = c_{21} = -El^2$$
$$a_{12} = b_{12} = a_{21} = b_{21} = 0$$

we obtain

$$\Delta_{22}(p) = \begin{vmatrix} 1 & , & -El^2 \\ 0 & , & ml^2p^2 + klp + 2El^2 \end{vmatrix} = (ml^2p^2 + klp + 2El^2) \qquad [21]$$

$$\Delta_{21}(p) = 2El^2 \qquad [22]$$

$$\begin{aligned} \Delta(p) &= (ml^2p^2 + klp + 2El^2)^2 - E^2l^4 \\ &= m^2l^4p^4 + 2kl^3mp^3 + (4Eml^4 + k^2l^2)p^2 + 3Ekl^3p + 3E^2l^4 \end{aligned} \qquad [23]$$

Let α_1, α_2, be the roots of Equation [21] and α_3, α_4, α_5, α_6 the roots of Equation [23]. Then Equations [20] become

$$\left.\begin{aligned} \psi_1 &= \frac{(p - \alpha_1)(p - \alpha_2)}{(p - \alpha_3)(p - \alpha_4)(p - \alpha_5)(p - \alpha_6)} Ae^{ipt} \\ &\qquad + B_{11}e^{i\alpha_3 t} + B_{12}e^{i\alpha_4 t} \\ \psi_2 &= \frac{2El^2}{(p - \alpha_3)(p - \alpha_4)(p - \alpha_5)(p - \alpha_6)} Ae^{ipt} \\ &\qquad + Be^{i\alpha_5 t} + Be^{i\alpha_6 t} \end{aligned}\right\} \qquad [24]$$

[1] O. Heaviside, Elec. Pap., vol. II, p. 371. An elementary presentation is given in Notes on Heaviside's Operational Method by M. S. Vallarta, M.I.T., March, 1923.

or

$$\left.\begin{aligned}\psi_1 &= \frac{(p-\alpha_1)(p-\alpha_2)}{(p-\alpha_3)(p-\alpha_4)(p-\alpha_5)(p-\alpha_6)}\,A\cos pt \\ &\qquad + B_{11}\cos\alpha_3 t + B_{12}\cos\alpha_4 t \\ \psi_2 &= \frac{2El^2}{(p-\alpha_3)(p-\alpha_4)(p-\alpha_5)(p-\alpha_6)}\,A\cos pt \\ &\qquad + B_{21}\cos\alpha_5 t + B_{22}\cos\alpha_6 t\end{aligned}\right\}\quad ..\,[25]$$

where p is the circular frequency of the disturbing force. The first term of the second members represents the forced components of the steady state and the succeeding terms represent the transient components. Similarly as in Equation [14], Equations [25] show that the transient oscillations of the different parts of the system have different frequencies; the resulting relative variation in phase and amplitude from point to point merely expresses the existence of elastic waves.

For simplicity the argument has been restricted to a system having two degrees of freedom, but the method can be applied to systems of this type with a finite number of degrees of freedom.[1] The general solutions are still represented by equations of the form of Equation [20], the determinantal equation $\Delta(p) = 0$ simply increasing in order.

We may conclude by inspection of the Lagrangian equations that in any mechanical system similar to those considered, be they treated as discontinuous or pseudo-continuous, when any of the constituent parts vary in potential or in kinetic energy, oscillatory displacements and dynamic stresses are set up. If the medium consists of a system of independent mass particles, Equations [15] express the solution. If the medium is pseudo-continuous, i.e., with elastic connections between the mass particles, Equations [20] express the state of motion and the corresponding state of stress.

The frequencies of the free components forming the transient components are given by the roots of the determinantal equation $\Delta(p) = 0$. The frequencies of the forced components, which are the oscillations of the steady state, are the frequencies of the impressed force components. The amplitude of the transient components are determined by the connections of the system and the initial configuration at the instant when the forces are applied. The amplitude of the steady-state components depends upon the frequencies of the impressed forces and the free frequencies of oscillation of the system.

Formulas for the dynamic stresses such as those proposed by Lasche, Marx, and Walker failing to take into account the necessary elastic constants of the material and the relation of the frequency of the free oscillating system and the frequency of the cyclically impressed force, are at least incomplete in their essentials.

Discussion

EARLE BUCKINGHAM.[2] The writer takes exception to the first paragraph of the paper. The existence of torsional vibrations and of the consequent stresses is known, but thus far reliable quantitative data have been lacking, so that it has received but scant attention in relation to the strength of gears.

In considering the oscillatory deformations with perfectly formed teeth it is stated that with no frictional forces the amplitude becomes infinite. But because of the presence of friction and mass and also of imperfect elasticity, these amplitudes and strains are materially dampened. The primary deductions are rightly based on ideal and non-existent conditions, and the resultant theory is deduced by considering the modifications introduced by the use of materials which do not meet these ideal or theoretical conditions.

This is exactly the same procedure as is followed in considering the stresses in gear teeth, due to inaccuracies of profile and spacing. Assuming rigid or indeflectible materials, any errors in form or spacing will introduce infinite stresses when such gears are in motion. But because of a certain amount of elasticity and lack of rigidity in the materials, the extent of such stresses is considerably modified. The great problem here, and also in regard to the torsional stresses, is to determine reliable quantitative values for these modifications.

The final solution must consider both classes of stresses. The torsional stresses can be kept at a minimum by proper proportioning of shaft and gear sizes, distances between bearings, etc., so that the critical speeds are kept outside of the operating speeds of the gear unit. To predetermine this with certainty, however, requires far more reliable data than at present are generally available. The photoelastic investigations now under way promise much assistance in this respect. The Gear Research Committee of the A.S.M.E., of which Wilfred Lewis is chairman, hopes to obtain reliable data in regard to the external forces which develop from errors in form and spacing of known amounts at various speeds. These two problems are complementary. Both must be solved to obtain the whole answer.

E. O. WATERS.[1] In the past we have been prone to believe that perfection in the forming and spacing of gear teeth is a sure cure for all sorts of gear troubles that arise when gearing is run at high speed; and, in accordance with this belief, the last quarter century has witnessed the development of machine tools that are marvels of ingenuity in design and accuracy in performance. Aside from all mathematical analysis, the author renders the valuable service of revising our preconceived notions and showing that, no matter how perfectly these teeth are formed, they are subject to the periodic stresses which any periodic force sets up in any elastic material, and furthermore that these same stresses may, for certain combinations of the independent variables, give rise to dangerous conditions.

Particular interest attaches to the possibility of resonance between the free vibrations of the gear teeth and the forced vibrations that are impressed by the periodic driving force. Might this not account for the marked ringing of a pair of mating gears running at a certain speed, in contrast with their comparative quietness at lower or higher speeds? Also the effect of the damping factor $krd\theta/dt$ in eliminating resonance and reducing the amplitude of all the vibrations may indicate the desirability of using soft, inelastic materials for high-speed gearing, even when large amounts of power are being transmitted.

The practical designer of gearing, after reading the paper, will naturally ask, "Now that we have these equations, what can we do with them?" In the first place, it seems clear that considerable experimentation should be carried out, both theoretically and in the laboratory, with changes in the independent variables—moment of inertia, specific elasticity, damping factor, magnitude and frequency of the impressed forces—to find out exactly what will happen under specific conditions.

In the second place, it ought to be possible to simplify the formulas considerably. In their present form it would appear that the labor of computing a large number of terms—anywhere from ten to a hundred or more—and then adding them, would be prohibitive. The trouble is that the impressed force $f(t)$ is actually a *discontinuous* function of the time. Each of the tangential forces $F_1, F_2, F_3, \ldots \ldots F_n$ has a large, approximately constant value for a short interval; and such a function would naturally require a great many terms of a Fourier series to express it with anything like reasonable accuracy. Would it not be simpler to divide the history of each point (1), (2), (3), etc., in Fig. 1 of the paper, into two parts—one in which the impressed force is constant or nearly so, and one in which the oscillations are "free"—derive equations for each of these parts, and then relate them by means of the boundary conditions which would be identical? The principle of superposition, which is applied is so as to obtain the combined effect of all the impressed forces, would involve as many additive terms as there are teeth in the pinion, and could be effected either graphically or algebraically according to the personal preference of the computer.

Undoubtedly what the designer wants is a *simple* corrective factor which he can apply to the ordinary equation for the static stress in gear teeth, in order to arrive at a fair approximation to the dynamic stress. It may take much time and effort to derive this factor, but the present paper is a step in the right direction, in that it shows us what variables should be considered, and, in well-generalized terms, what the relations are which bind these variables together.

M. S. VALLARTA.[2] The close analogy between non-radiating oscillating electric circuits and oscillating mechanical systems has been well-known for about a century, but it is only very recently, perhaps for the first time in the paper presented by the author, that the

[1] J. R. Carson, *Phys. Rev.*, vol. 10 (1917), p. 217.

[2] Engr., Pratt and Whitney Co., Hartford Conn. Assoc-Mem. A.S.M.E.

[1] Asst. Prof. Mch. Design, Yale University, New Haven, Conn. Jun. A.S.M.E.

[2] Mass. Inst. of Technology, Cambridge, Mass.

methods developed by the genial intuition of Oliver Heaviside have received an important application to a practical mechanical problem.

Heaviside's method may be briefly summarized as follows: For the sake of concreteness, consider a particle m_n in a pseudo-continuous medium such as defined by the author, and let it be required to find its motion under the influence of an external force $F = f(t)$ applied at another remote spot of the same medium. Then, as shown in the paper, the Lagrangian equations of motion yield, for the m particles of the pseudo-continuous medium, a system of m equations of the form

$$(I_{11}p^2 - R_{11}p - E_{11})x_1 + (I_{12}p^2 - R_{12}p - E_{12})x_2 + \ldots\ldots + (I_{1m}p^2 + R_{1m}p + E_{1m})x_m = F$$

$$(I_{12}p^2 + R_{12}p + E_{12})x_1 + (I_{22}p^2 + R_{22}p - E_{22})x_2 + \ldots\ldots + (I_{2m}p^2 + R_{2m}p + E_{2m})x_m = 0$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$

$$(I_{m1}p^2 + R_{m1}p + E_{m1})x_1 + (I_{m2}p^2 + R_{m2}p + E_{m2})x_2 + \ldots\ldots + (I_{mm}p^2 + R_{mm}p + E_{mm})x_m = 0$$

where the I's are the coefficients of inertia, the R's the frictional coefficients, the E's the stiffness coefficients of the m particles, and the x's are their corresponding coördinates.

From this system of equations, $m - 1$ may be eliminated, yielding for the nth coördinate x_n, which determines the motion of the nth particle.

$$X_n = \Delta_n(p)F$$

$\Delta_n(p)$ being a function of the time derivative p involving also the coefficients of inertia, of friction, and of stiffness. This will be called the *operational solution*. It is now required to integrate this differential equation. For this purpose Heaviside invented a new process which he called *algebrization*, which may be looked upon as a far-reaching generalization of symbolic calculus, and which enables us to obtain the integrated solution embodying the terminal and initial conditions of the problem. As an alternative, Heaviside gave in his celebrated Expansion Theorem a general method for the conversion of the operational solution to the explicit solution, expressed in terms of an expansion in normal functions. In the present paper, the author has used the fundamental ideas involved in the method of the Expansion Theorem to obtain his final solution [24].

It might be emphasized that the Expansion Theorem enables us to find *at once*, without any intermediate calculation, the explicit solution of any linear differential equation with constant coefficients; for example, the expression describing the modes of oscillation of a particle in a pseudo-continuous medium can be instantly written down. Moreover it should be noted that the Expansion Theorem has been established rigorously by K. W. Wagner for the case of a constant applied force,[1] and by J. R. Carson for the case of a force which can be described by an exponential (real, imaginary, or complex) function of the time.

Attention might also be called to the fact that if the applied force can be described by a function

$$F = Ae^{pt}$$

when p is real, imaginary, or complex, the form of p fixes the form of the time derivative d/dt; for, in fact,

$$\frac{dF}{dt} = \frac{d}{dt}Ae^{pt} = pAe^{pt}$$

and $d/dt = p$, formally. For example, if $F = A \cos \nu t = Re\, Ae^{j\nu t}$ (where Re = real part), then $p = j\nu$, a familiar result for electrical engineers. This fact is made use of by the author in setting up Equation [18] in the paper.

R. Eksergian.[2] The author states that there appears to be a tendency to attribute the existence of the dynamic stresses solely to the irregularities of the teeth and to assert that the stresses with perfectly formed and spaced teeth under a dynamic torque and the same torque statically applied are the same. This statement is somewhat inconsistent with a mathematical discussion contributed by the writer to Messrs. Heyman's and Kimball's paper on Stress Distribution in Rotating Gear Pinions as Determined by The Photoelastic Method, presented at the A.S.M.E. Annual Meeting in 1923. The mathematical part of this discussion will be given here in order to point out three major aspects that the analysis shows: (1) That a cause of disturbance may be due to the irregularity of the teeth and this disturbance may be shown to be exactly equivalent to an external periodic impressed force on the system; (2) that the elasticity of the system itself may alter the dynamic loading, and (3) that the periodic disturbance may be also due to actual external periodic variations of the applied or resisting torque of the motor or brake. It is admitted by the writer, however, that continuous media were not considered, there being assumed concentrated mass portions connected by elastic constraints, and to approach a possible multiple mass and elastic system would lead to complexity by the method to be outlined. Of course, the dynamic torque and static torque are *the* applied external torque considered by the author, but the question is still open whether the static stresses for a given applied force, say, applied periodically very slowly, would differ much from the stresses resulting from an applied periodic force corresponding to tooth frequency or some low multiple thereof. In other words, is not the natural period of vibration of the gear itself of very high order? The cantilever teeth of course may have considerable flexibility, but this flexibility could possibly be reduced to an equivalent shaft and the analysis could proceed as given below. The solution of Lagrange's equation even for the relatively simple system given in Fig. 3 is shown to be complicated, and it would appear that as simple an analysis as possible consistent with safe approximations is highly desirable. The value of the analysis given by the author, therefore, is in making it possible to answer such questions and thus reducing the final mathematical analysis to the greatest simplicity possible. It is to be particularly noted that the periodic applied forces that might agree with the probable high frequency of the gear itself would likely be of very small amplitude and would, moreover, be effectively damped by molecular friction should the stresses approach high values.

Let r = gear ratio of transmission = $\dfrac{\text{no. teeth on gear}}{\text{no. teeth on pinion}}$

$T_d' = rT_d$ = driving torque on pinion shaft reduced to equivalent torque on shaft (ft-lb.)

T = mutual torque between pinion and gear referred to gear shaft (ft-lb.)

T_r = resisting torque on gear shaft (ft-lb.)

$I_a' = r^2I_a$ = moment of inertia of armature reduced to gear shaft

I_w = moment of inertia of wheels, etc., on gear shaft

w' and w = angular velocities of pinion shaft and gear shaft referred to gear shaft

$C_a' = r^2C_a$ = elastic constant for torque due to elastic element in pinion shaft

C_w = elastic constant for the torque due to elastic element in gear shaft

Then for the fundamental dynamic equations we have

$$T_d' - T = \frac{dw'}{dt} \qquad [1]$$

$$T - T_r = \frac{dw}{dt} \qquad [2]$$

$$\frac{dw'}{dt} - \frac{dw}{dt} = \frac{d^2(\Delta\varphi)}{d^2t^2} \qquad [3]$$

where $\Delta\varphi$ is obviously the relative angular displacement referred to the gear shaft. Solving Equations [1], [2], and [3],

$$T = \frac{I_a'I_w}{I_a' + I_w}\frac{d^2(\Delta\varphi)}{dt^2} + \frac{I_w}{I_a + I_w}T_d' + \frac{I_a}{I_a + I_w}T_r \qquad [4]$$

The mutual torque reaction between the inertia system, however, can be measured by the several elastic deformations, that is,

$$T = r^2C_a\Delta\varphi_a = C_w\Delta\varphi_w \qquad [5]$$

[1] *Archiv. für Elektrotechnik*, vol. 55 (1916), p. 159.

[2] Engr., Baldwin Locomotive Works, Philadelphia, Pa. Mem. A.S.M.E.

Now the relative angular displacement reduced to the gear shaft between the inertia system is

$$\Delta\varphi = \Delta\varphi_a + \Delta\varphi_w + \Delta\varphi_g \qquad [6]$$

where $\Delta\varphi_g$ is the relative angular displacement between the pinion and gear wheel reduced to the gear shaft due to irregularities in the tooth contour. Therefore

$$\Delta\varphi = T\left(\frac{1}{r^2C_a} + \frac{1}{C_w}\right) + \Delta\varphi_g = \frac{T}{C} + \Delta\varphi_g \qquad [7]$$

where

$$\frac{1}{C} = \left(\frac{1}{r^2C_a} + \frac{1}{C_w}\right) \qquad [8]$$

Hence the dynamic equation reduces to

$$\left(\frac{I_a'I_w}{I_a' + I_w}\right)\frac{d^2(\Delta\varphi)}{dt^2} + C\Delta\varphi = C\Delta\varphi_g + \frac{I_w}{I_a' + I_w}T_d' + \frac{I_a}{I_a' + I_w}T_r \qquad [9]$$

To account for the irregularity of the tooth contour, we have a periodic function for $\Delta\varphi_2$, that is,

$$\Delta\varphi_g = A \sin nwt \text{ for the primary harmonic} \qquad [10]$$

where A = amplitude of primary harmonic of the relative displacement

n = number of teeth on gear wheel

w = mean angular velocity of gear wheel

To account for the pulsation of the driving torque we have

$$\left.\begin{aligned} T_d &= T_{do} + B\sin nwt \\ T_d' &= rT_{do} + rB\sin nwt \end{aligned}\right\} \qquad [11]$$

The fundamental equation simplifies to

$$M\frac{d^2(\Delta\varphi)}{dt^2} + C\Delta\varphi = A\sin nwt + D\sin(mwt + \alpha) + R$$

where

$$M = \frac{I_a'I_w}{I'_a + I_w};\quad C = \frac{C_wr^2C_a}{r^2C_a + C_w};\quad D = \frac{rBI_w}{I_a' + I_w}$$

$$R = \frac{rT_{do}I_w}{I_a' + I_w} + \frac{T_rI_a}{I_a' + I_w}$$

When the natural frequency of the stress $f = \frac{1}{2\pi}\sqrt{\frac{C}{M}}$ agrees with either of the periodic functions, the stresses in the teeth will reach high values. To reduce these stresses, since the periodicities of the periodic vibrations are high, the natural frequency would be made low; that is, C should be made as small as possible, which implies maximum flexibility between the two inertia systems.

From Equation [4] or [9], assuming $T_d' = T_r$ approximately, the torque reaction between the gearing pair becomes

$$T = \frac{I_a'I_w}{I_a' + I_w}\,\frac{d^2(\Delta\varphi)}{dt^2} + T_r$$

If the shafting, etc. is relatively stiff, $\Delta\varphi = \Delta\varphi_g = A\sin nw$, and therefore the dynamic loading is proportional to the square of the speed. On the other hand, if the elasticity between the gearing pair is considerable,

$$T = C(\Delta\varphi - \Delta\varphi_g)$$

and thus the dynamic loading can be reduced by increasing the elasticity of the system, that is, by reducing C, where $\Delta\varphi_g$ becomes small compared with $\Delta\varphi$. At this latter case the dynamic loadings can only become large when the natural frequency of the system agrees with the forced oscillations due to the irregularity of teeth; i.e., $A\sin nwt$. Hence, severe dynamic loadings can be avoided by tuning the gear pair away from the resonance condition.

Now to take into consideration the elasticity of the teeth and reduce this to an equivalent elastic torque, we must know the teeth in contact at any instant and the direction of the resultant mutual reaction between the gear teeth of a pair as well as a consideration of a possible distributed load.

As a first rough approximation, let l = cantilever length of load to cross-section at root of tooth, and I = moment of inertia of root section; then

$$\Delta\varphi = \frac{T}{R^2}\,\frac{kl^3}{3EI}$$

where T = torque on shaft, K = proportional factor, and R = radius to pitch line. So, in general,

$$T = C\Delta\varphi$$

where

$$C = \frac{3EI}{kl^3}R^2$$

thus reducing the teeth elasticity to a coördinate of the shaft.

One word further as to the derivation of the author's equation. In the potential function for use in Lagrange's equation the system is shown by diagram to represent a simple system of discrete particles connected by elastic connections. The displacements with respect to the vertical are ξ_1 and ξ_2, while the relative displacement between 1 and 2 is $(\xi_2 - \xi_1)\sin\varphi$, where φ is the angle between 1–2 and the vertical. If E is the elastic constant, the potential energy due to the vertical connection is $(\xi_2 - \xi_1)^2\sin^2\varphi$. In the limit 1 and 2 are practically collinear, hence the disappearance of $\sin^2\varphi$. From another point of view (1) and (2) may be elementary cantilever springs; then $\xi_1 = Fl^3/3EI = F/E$, where $E = 0.3EI/l^3$ and F is the component reaction. Hence the energy stored is $F\xi/2 = E\xi^2/2$. Further, since the coördinate of the relative displacement between 1 and 2 may be angular as well as linear, the elastic reactions exerted on 1 and 2 due to the mutual constraint are not necessarily collinear. This shows the generality in the treatment of the elastic connections in the building up of the Lagrange equation.

The independent coördinates are taken as the angle of the radial lines to the discrete particles. Therefore the complete solution would involve an infinite number of equations and would likely be considerably more complicated. Could not the elastic distribution be approximated by the aid of experiment, so that a more simple and direct solution could be made and the number of independent coördinates possibly be reduced?

The Author. The statement made in the first paragraph of the paper primarily refers to a one made in a recent paper[1] of Wilfred Lewis, in which Mr. Lewis says that he now believes that the stresses with perfectly formed and spaced teeth are the same under a dynamic torque than they are under the same torque statically applied. Mr. Waters in the first part of his discussion confirms the fact that the solution for gear failures has not been sought for in the dynamic stresses existing even with perfectly spaced and formed teeth. In a recent discussion of a previous paper of the author's, Mr. Erksergian has indeed pointed out the dynamical character of the stress problem in rotating gears.

The work of confirming experimentally the mathematical derivations presented in this paper and of putting them in form available for practice is being continued by the author in coöperation with A. L. Kimball, Jr., and J. L. Williamson of the General Electric Co., and T. H. Frost of theMassachusetts Institute of Technology.

Electricity was recently used for operating a threshing machine at a farm near Bloomington, Ill. As recorded by the Illinois Power and Light Corp., 133 bushels of wheat were thrashed per hour in a threshing machine driven by a 40-hp. motor connected through a transformer to the transmission lines already in position. The estimated cost of current is approximately twenty-five dollars per day of eight to ten hours. The cost of operating a traction engine, not including wages, is approximately twenty dollars. Electric equipment including motor, transformer, wages, etc., was approximately \$1300 compared to the average cost of a traction engine at \$4000 and a high-powered tractor at from \$2000 up. The electric motor apparently simplified the operation and reduced the element of fire danger. The objection of high operating cost is the only one apparent.

[1] Modern Problems in Gear Testing and a Proposed Testing Machine *American Machinist*, Dec. 13, 1923, p. 875.

Combustion Control for Boilers

Functions Involved in Operation; Possibilities and Methods of Regulation; Design, Installation; the Human Factor in the System

By R. J. S. Pigott,[1] New York, N. Y.

The problem of combustion control for boilers is certainly not a new one, since it started in the days when hand-fired grates were the rule rather than the exception. Innumerable contrivances have been invented and more or less successfully marketed which have purported to improve the efficiency of boilers. But the great majority never had any inherent ability to improve efficiency, since they either controlled the wrong thing, or controlled the right thing incorrectly.

In view of the great diversity of method even today in applying automatic control to boilers, it seems that there is still a great deal of misunderstanding as to what combustion control really is. It would therefore not be out of place, perhaps, to go back to basic facts, and examine why it is we need any automatic control, and what functions we ought to control.

Functions Involved in the Operation of a Boiler

There are four distinct functions involved in the operation of a boiler:

a Supplying air in the proper proportion to burn the fuel

b Supplying fuel at a rate sufficient to maintain the required steam output

c Mixing the air and the fuel, and burning them at a suitable temperature to result in as complete combustion as possible

d Absorbing the generated heat into the boiler proper.

The first function is, of course, based upon the chemical requirements of burning fuel, and is determined both by the amount of oxygen required per pound of fuel to burn it completely, and by the excess over this amount that is called for by the *imperfect mixing* provided by the fuel-burning device (such as a hand grate or a stoker). It is a convenient fact that the air required per 10,000 B.t.u. of any commercial fuel, from lignite to oil, is 7.6 lb., within 2 per cent; but this is of no help to regulation since the requirements of the fuel as fired vary from 6 to 14 lb., for reasonably complete combustion.

The excess air required is very largely determined by the firing equipment, and in a much smaller degree by the furnace. The hand grate usually requires from 60 to 80 per cent of excess air to get its best results under good operation; the older overfeed stokers, 55 to 65 per cent; the modern chain grates and underfeed stokers 40 to 55 per cent; powdered-fuel burners or oil burners, 15 to 25 per cent; surface combustion with gas, no excess air. These variations are almost wholly due to the difference in thoroughness of mixing the air and the volatile combustible.

Once the fuel, the fuel-burning equipment, and the furnace are chosen, the air-fuel ratio is largely fixed, and will remain so unless the character of the fuel, the temperature in the furnace, or the mixing is changed. This factor is one that can be automatically controlled, for the most part, and is the most important one affecting efficiency.

The second function, regulation of fuel supply in accordance with output, constitutes the control for capacity, in order that the steam pressure should not fall too low to operate the connected prime movers, or rise above the popping pressure of the safety valves. It is worth while at this point to state emphatically that there is not and never has been, any direct connection between constant boiler pressure and efficiency.

The earliest form of automatic-control apparatus was the damper regulator of the diaphragm, weight-loaded type; this device aimed at opening the damper when the steam pressure dropped below a definite pressure, or closing it when the pressure rose above the set point. Elaborate compensating devices have been applied to this type of regulator, but since the actuating mechanism, a dead-weight-loaded diaphragm, was inherently in unstable equilibrium, it had to be either all the way up, or all the way down; consequently the damper would always be either wide open or tight shut, and the compensation was ineffectual. That this sort of regulation, whether applied to air or to coal feed, is absolutely wrong, many engineers are undoubtedly convinced by their own experience. It should be clear that regulation to constant pressure cannot give proper capacity regulation. There is only one way in which this function can be satisfied, and that is by quantity measurement of coal into the furnace in some suitable relation to steam output. To satisfy the first function, i.e., proper proportioning of air and fuel, the air must also be simultaneously quantity-measured according to the same relation.

It is evident from a consideration of the input-output curve, or the efficiency curve of any boiler that the ratio of fuel to steam is not the same at different loads. Fig. 1 shows these curves for various kinds of firing equipment under normal conditions of installation, if one may use such a term in connection with modern boilers.

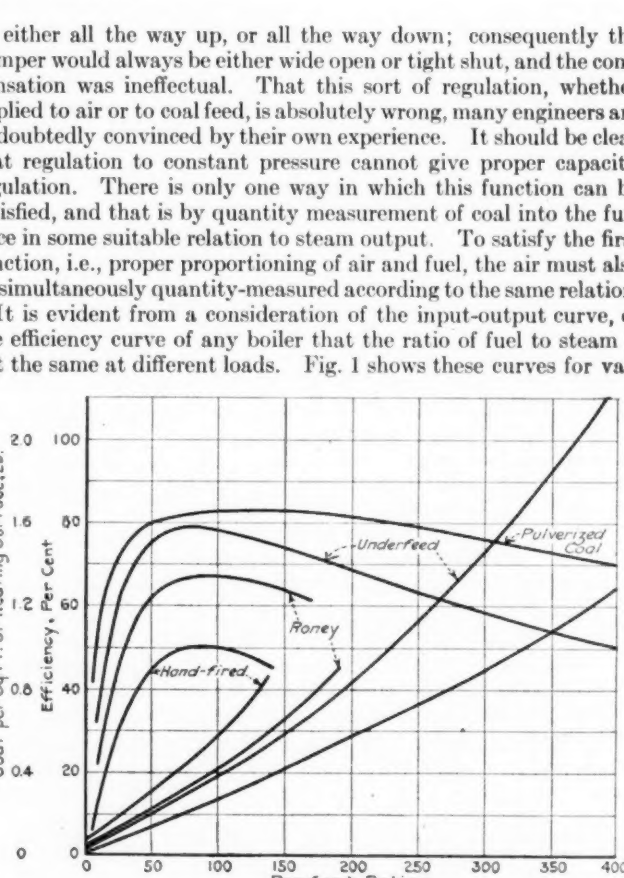


Fig. 1 Operating Efficiency and Input-Output Curves for Various Firing Equipments

(14,000-B.t.u. coal; Ratio heating surface to grate surface, 50.)

Although the ratio of amount of fuel and air to steam is not a constant one, it follows a fairly regular law, and it is certainly possible to provide automatic quantity regulation of fuel and air in proportion to steam output.

The mixing of air and fuel is largely determined in operation by the firing apparatus and the furnace. The hand grate and most overfeed stokers were about on a par in this respect, and undoubtedly were rather poor. Stratification has always been very pronounced with the inclined-grate overfeeds, and is generally perceptible in most of the chain grates. There is relatively little stratification with underfeed types of stoker, since the method of introducing air and coal gives a much better natural mixing. Stratification is almost entirely absent in powdered-coal firing, and in surface-combustion furnaces (gas-fired) there can be none. Furnace temperature is chiefly dependent upon excess air; the less excess air the higher the furnace temperature, as a rule.

It is a curious fact that boiler tests at very high efficiencies have been obtained with all types of firing. Efficiencies of 81 and 82 per cent have been obtained in England with hand firing, 82 to 83 per cent with underfeed stokers, and as high as 85 per cent with powdered fuel. But compare these figures with the average operating performance: those for hand firing are about 25 to 30 per cent below possible test performance; for overfeeds, about 18 to 20; for underfeeds, about 10 to 12; and for powdered coal, about 3 to 5. The difference is by no means all in the inherent qualities of the apparatus used.

[1] Stephens & Wood, Inc., N. Y. C. Mem. A.S.M.E.

Presented at a meeting of the Metropolitan Section of The American Society of Mechanical Engineers, New York City, April 30, 1924.

It is perfectly true that it is always easier to get better efficiency from an underfeed stoker than from hand firing, by virtue of its inherently better mixing conditions, but this is only part of the difference. The other factor is the human supervision. Hand control is *essentially intermittent;* whereas the demands of varying load call for regulation every moment. Automatic regulation can unquestionably lessen the difference between attainable efficiencies and ordinary monthly peformances, by keeping the essential ratios on the mark 100 per cent of the time; with hand control they are undoubtedly off the mark more or less all of the time. An automatic regulator may get out of order, but it does not get tired.

One great difficulty with all fuel-burning devices employing a bed of coal is the heat storage therein. It is bad enough for control purposes to have steam storage in the drums, but in controlling a stoker no one can tell the effect of a change of conditions for some time after the change has occurred; meantime, some other condition may have altered, which will completely mask the effects of the first change. In this respect powdered coal and oil have an advantage. Having no heat storage in fuel, the effect of a change is instantaneous, and readily detected. This accounts for the small difference between operating and test efficiencies.

The last function, absorbing the heat into the boiler, is a function of design, and is not materially affected by regulation, except in so far as the latter may affect furnace temperature and excess air. For our purposes it may be disregarded for the present.

Possibilities of Regulation

From the foregoing consideration of the factors involved in firing the boiler, it should be self-evident that, in order to get the best possible efficiency out of a boiler installation, the fuel must be fed into the furnace every instant, with exactly the amount of air per pound of fuel required to burn it fully in the firing apparatus provided; and for proper output both fuel and air must be supplied every instant in proportion to the steam output. To do this by hand requires simultaneous continuous observation of, say, seven indications—steam flow, steam pressure, CO_2, stoker or feeder speed, uptake draft, furnace draft, and air blast—as usually provided hitherto. In addition the operator must also see that his stoker is kept in proper condition of fire. It needs no demonstration to prove that such a set of conditions cannot be physically met. Add to the above the storage effect of coal on the stoker, masking any results of adjustments the operator may make, and the case is still more difficult. Lastly, add to the above the knowledge that static pressures in drafts and blast do not tell the operator what he needs to know, namely, the quantity of air supplied, and it becomes a matter of surprise that the operating efficiencies of stoker plants are as near the test efficiencies as they are.

The pulverized-coal-fired boiler eliminates one of the difficulties—heat storage due to a fuel bed—so that adjustments produce immediately visible results. Furthermore there is little or no distraction of the operator's attention from control, since there is substantially no "conditioning" of the fire to be performed. But the problem is nevertheless there. Continuous observation and adjustment of air and fuel quantity to steam output cannot be performed by a human being.

What we actually have been doing in hand regulation is to make adjustments at intervals, so that the only possibility of the ratios being on the mark is at the time of adjustment; at all other times the ratios must be either too high or too low, unless the boiler load is *absolutely* constant, a condition that is practically unknown.

The penalty we have been paying for intermittent adjustment, and improper measuring of quantities, is the difference between best efficiencies and operating efficiencies. This loss, as previously indicated, has averaged 18 to 20 per cent for overfeeds, 10 to 12 per cent for underfeeds and 3 to 5 per cent for powdered fuel. This loss will always pay for almost any investment likely to be required by automatic regulation.

There is another, though smaller, advantage to be gained from automatic control, and that is also largely due to the fact that the regulator is functioning all the time. This advantage is the immediate adjustment of fires in case of sudden drop or increase in load. Under hand regulation a sudden loss of load, such as that due to a heavy short-circuit in a transmission line, usually builds up pressure so fast that the safety valves pop for several minutes before the fires are reduced: this is a very material loss, though not generally measured. In the case of sudden increase of load, such as that due to loss of a unit in another station on the system, the drop of pressure due to increased demand may be quicker than the response of the operators to the emergency. Once the pressure gets down materially the water rate of the turbines is increased and the steam demand still further enlarged. This results in dropping the pressure so as to endanger the carrying of the load. If the automatic regulation is adequate, adjustment of fires begins the instant the steam demand changes, and the situation will not get out of hand.

Before we can either control by hand or automatically however, we must accomplish at least three things fairly accurately. We must meter the steam output, the fuel, and the air input. We have hitherto neglected to do this, as can readily be shown. We often measure steam output, usually by flow meter; but we have almost never attempted to measure rate flow of fuel input; ordinarily we have either left this function to a guess by the operator, or have left it to a so-called regulator operated by blast pressure. With regard to air, we have been deluding ourselves with the belief that static drafts on blast or uptake were measurements of flow; they generally are not. The uptake draft, if the furnace draft is kept constant, is a good measure of rate flow of flue gases, provided also that the boiler passages are always kept in the same state of cleanliness. Under all other conditions, it is of little value. But blast pressure for a stoker is never a reasonable measure of flow since for any given flow it may be altered from 50 per cent to 100 per cent by changes in the fuel bed.

The only static pressure in which we are interested is the furnace draft. This must be kept slightly negative, to avoid overheating stoker fronts and doors or blowing out flame or powdered coal, but must be kept as near zero as practicable to keep down setting infiltration.

Methods of Accomplishing Regulations

To establish automatic control, we must

a Meter the steam flow
b Meter the coal feed in proportion to the steam
c Meter the air in constant ratio to the coal
d Keep the furnace draft slightly negative.

The first impulse must come from steam flow, since this is the primary variable to which we must adjust the others. The device may be either the elements of a flow meter or pressure drop due to friction (which is really a form of flow meter).

It must be definitely recognized that the primary impulse must not in any case be a device aimed at holding constant pressure at the boiler outlet, or anywhere else, because this is setting up a system analogous to an isochronous governor on a turbine; we cannot govern to absolutely constant speed in a turbine without instability; we must permit a slight *change* in speed with load in order to provide a stable governor. Similarly, we cannot produce stable equilibrium in any automatic regulator without allowing a pressure change with load.

The primary impulse from the steam flow must actuate the fuel feed in proportion to this flow, and the device must so operate that a given change in steam flow produces a definite proportional change in fuel flow; in other words, the regulator must be compensated. We have fairly good means ready to hand for metering coal flow. If coal is reasonably evenly sized and its moisture is fairly constant, the speed of the stoker chain or ram crankshaft is a sufficiently accurate measure of coal rate flow by volume. Or in the case of powdered fuel, if the moisture is fairly constant and the powdered coal is kept in about the same condition of aeration, the speed of the feeder screws is a satisfactory measure of the fuel rate.

Similarly, air flow must be regulated either directly from the steam flow, or from the coal flow, and must be compensated likewise. We may measure the air flow by the draft loss across the boiler surface, which is the difference between the uptake draft and the furnace draft. This measures flue gas, it is true, but since the ratio between flue gas and air is a constant, provided the coal-air ratio is not altered, it is practically as satisfactory as measuring the air direct, and in some cases may be more convenient. We may also measure the air direct by means of a disk orifice, venturi, or any other flow device that gives a static difference corresponding to flow.

There are three ways these three operations may be interlinked:

a Steam flow actuates fuel flow, fuel flow actuates air flow
b Steam flow actuates air flow, air flow actuates fuel flow
c Steam flow actuates air and fuel flow simultaneously.

The control of furnace draft has nothing to do directly with the three metering functions, since it has nothing to do with rating But it is desirable to control furnace draft for the reasons given above, and this control must be so arranged as not to interfere with the metering functions.

Requirements of Regulator Design

There are four characteristics which must be embodied in any successful automatic combustion-control system. The regulator must be:

a Stable
b Sensitive and speedy
c Reliable
d Powerful.

The stability depends upon the elimination of constant-pressure regulation and upon the character of the compensation. Sensitiveness (which must also include accuracy and speedy response) should be high, or else the regulation will not improve much over hand regulation. It must be reliable—as rugged and simple as may be—or it has no place in a power plant. It must be about five times as powerful as the designer believes the resistance to be; dampers, controllers, and throttles have all been known to stick. It is worth observing that it is no easy task for the designer to get out a mechanical contrivance that will meet all the requirements mentioned.

The author believes that the day of individual regulators—working more or less independently, and receiving their impulses to operate from purely static pressures—is definitely gone by, and that we must now think of all boiler regulation in terms of flow only. It is satisfactory therefore, to know that one or two systems are already working, employing this principle successfully, and there may be more.

Matters Regarding Design, Installation, and Operation

We have so far considered the purely mechanical side of the problem, but there is in addition a very important factor involving the human element, and this element can make a regulation system successful or completely destroy its usefulness, according to the attitude of the plant designer or the operator.

It has generally been the custom to buy such regulation as was available in uncorrelated units. For example, steam-pressure-operated regulators would be applied to the fans—maybe two or twenty, entirely unconnected and acting perfectly independently; then air-pressure-operated regulators to the stoker engines, equally unconnected with each other or with the fan regulators; then another set of regulators to the uptake dampers, working from furnace draft, and so on. Such a collection of regulators was not designed to function as a completely interconnected system, with one controlling impulse, and consequently, at least in the author's experience, has never been able to function except by accident.

These regulators have always been applied as an afterthought with the consequent handicap of limiting the application to the detriment of results. It is necessary that power-station designers consider automatic regulation as a part of the design, just as heat balance, and provide for application of the regulation system so that it is free to function as a completely synchronized group of devices.

Up to very recently there has been no means of centralized control of the boiler room, in the manner that the electrical operations are controlled. It is not only possible to do this, but it is necessary to the best operation of the plant. If automatic regulation is applied throughout a boiler room, it is relatively easy to provide "bench-board" control of the whole of the boiler functions. One of the principal supervision weaknesses of the usual boiler plant is that there is no means of calling attention to the abnormal; it is discovered largely by accident. The whole value and intent of supervision is to find and correct the abnormal: the normal needs no attention.

In our Lowellville station we have applied such a centralized control, in such a way that the combustion engineer may, from the control room, accomplish the following results:

a Control the steam pressure of the whole plant
b Detect a dirty fire
c Note a fire being cleaned
d Detect dirty gas passages
e Detect trouble with any regulator
f Detect a boiler above or below the average rating
g Detect any unbalance in the fan delivery
h Notify the fireman which boiler needs attention
i Receive, transmit, and prepare for any changes of load
j Note the average boiler rating indicating when to cut in or cut out boilers
k Note gas analysis of any boiler
l Note flue temperature of any boiler.

Such centralized control gives a completely new opportunity for effectual supervision. The results, even in so short a time as this installation has been operating, are so satisfactory as to remove any question of the desirability of automatic regulation, and its advantages.

In operation there are two major troubles that tend to destroy the performance of any regulation system: first, the general disbelief that any mechanical contraption can possibly regulate a fire as well as an experienced fireman; and second, expecting the apparatus to do things without attention or supervision that do not lie in its power.

The organization operating the boiler room must be educated to recognize that a regulating system takes 80 to 90 per cent of the observing and adjusting operation from the fireman, and leaves him entirely free to do what the regulation cannot possibly do—keep the firing equipment in proper condition to do what the regulation demands of it. The regulation can supply the proper quantities of air and fuel in proportion to steam, but it cannot clean a fire, dump ashes, nor clean the boiler.

Generally a fireroom force is firmly convinced that a good fireman is the best judge of firing conditions, and that regulation is only a fair approximation to a good fireman. That this is a false belief has already been amply proved by actual demonstration, but in every plant a campaign to overcome this prejudice must be carried through, or else the results possible with automatic regulation will never be realized. The active support of the operating force must be enlisted.

To sum up, it is demonstrable that automatic regulation of boilers offers advantages in efficiency and control of capacity; it can provide a central control of the boiler room which hitherto has been lacking. The principles which must govern its design are clearly established, and the designer and operator must be "sold" on it to make it a success. It remains only to consider the actual commercial design by which regulation is to be accomplished.

In the last Grand Prix race, on August 3, twenty-two cars were entered originally with supercharger devices used on eleven machines. The three leading cars, Sunbeam, Fiat, and Alfa-Romeo, were all supercharged.

The Fiat had a supercharger placed after the carburetor, with the cooling device between the front dumb irons through which all the air is passed before going to the blower.

The Sunbeam had the carburetor mounted ahead of the blower near the front of the engine. This carburetor was connected up to the ribbed blower mounted on the front end of the crankshaft and ran at engine speed. To overcome any possibility of damage by reason of a blowback into the compressor, there was a relief valve opening outward immediately at the base of the intake manifold, allowing an exploded charge to pass outside the head. It is said that excellent results were obtained from the use of this device, including an increase in power at all engine speeds from 2200 r.p.m. up.

The supercharger on the Alfa-Romeo cars (winner of the race) was mounted on the front end of the crankshaft, drawing in air around the base of the radiator and delivering it through a cast-aluminum conduit bolted to the right-hand side of the engine between the base chamber and the flame member. The carburetor (Italian Memini) was bolted to the top of this air conduit, the base of which was ribbed for cooling purposes. The engine is stated to have developed 140 hp. at 5500 r.p.m. Fiat claimed their engine showed 150 hp. and the Sunbeams were said to give 145 hp. on the brake. (W. F. Bradley in *Automotive Industries*, vol. 51, no. 6, Aug. 7, 1924, pp. 276–279, 4 figs., *d*)

Heat Losses through Insulating Materials

A Rational Method for Their Determination by Means of the Conductivity Coefficients of the Materials

By R. H. HEILMAN,[1] PITTSBURGH, PA.

With the higher temperatures due to the use of superheated steam in power plants, the problem of providing suitable pipe and boiler insulation is becoming a difficult one. The present paper is therefore timely in that it includes the results of numerous and exhaustive tests on commercial pipe coverings and insulating cements, which are presented in curves, tables, and formulas that can be readily used by the engineer. Interesting experimental methods are described and the exact character of thermal conductivity and its relation to temperature gradients and differences is discussed from a physical and mathematical standpoint.

THIS paper presents the results of 94 tests on commercial pipe coverings and insulating cements conducted at Mellon Institute of Industrial Research of the University of Pittsburgh. The overall losses through sections 1 in., 2 in., and 3 in. thick are included, together with the thermal conductivity for each brand of material tested. Curves and tables are also presented which will facilitate the calculating of heat losses through single and compound sections.

The present tendency in steam power plants and industrial plants of various types to increase their steam temperature by means of superheat has caused the manufacturers of pipe and boiler coverings to renew their efforts to provide suitable insulations and specifications to keep pace with the increasing temperatures.

Some manufacturers are specifying the use of an inner covering next to the pipe which has a high resistance to the effects of heat, with an outer covering having not so high a resistance to the effects of heat but having a lower conductivity value. The inner covering should be applied in sufficient thickness to lower the temperature at the inner surface of the outer covering to a point where the physical structure of the covering will not be appreciably affected by the heat.

Very little information is available which will enable one to calculate accurately the loss of heat through single and compound sections for various conditions as well as determine temperatures at the surfaces of compound sections, and the purpose of this paper is therefore to present in a rational form the conductivity values obtained from the most important types of coverings now on the market.

Description of Testing Apparatus

The electrical method of testing is used at the Institute, as this method has proved to be the most accurate in addition to being more easily controlled. The apparatus now used is the gradual development of practically seven years' work on heat insulations, and it is believed that it is sufficiently accurate to measure the slight difference in conductivity value which exists between certain coverings which are otherwise apparently identical.

The test pipes are 3-ft. sections of standard 3-in. steel pipe closed at the ends with insulating caps and containing three heating coils connected in multiple and wound on an enameled steel pipe. A variable resistance is placed in series with each of these coils to provide a means of regulating the heat supplied to each coil. While the covering being tested is drying out, the power input to each coil is adjusted until the temperature as indicated by the thermocouples placed in the test pipe is the same over the end coils as that over the central coil.

When this condition is reached it is assumed that the power supplied to the central coil is dissipated radially through the covering, thus eliminating any further correction for end losses.

Copper-constantan thermocouples consisting of No. 29 copper and No. 29 constantan wires electrically welded together are used in making all temperature measurements with the exception of the room temperature, for which high-gra demercury thermometers are used. The thermocouples for measuring the pipe temperature are peened into a No. 57 drill hole about $^1/_{32}$ in. deep and great care is taken to see that the thermocouple junction does not extend above the surface of the pipe, since carefully conducted tests have shown that if the junction extends very slightly above the pipe surface lower temperatures than actually exist are recorded.

The e.m.f. generated by the thermocouples is measured with a Leeds and Northrup precision potentiometer built especially for thermocouple work, while the power supplied to the heating coils is measured with Weston indicating wattmeters. The supply voltage is kept very constant by means of a General Electric saturated-core-type voltage regulator designed especially for the Institute laboratory.

The coverings are all measured for thickness with a jeweler's gage which is capable of reading to .001 in. Thirty readings are taken on each 3-ft. section and the average of the 30 readings is taken as the thickness of the covering.

Description of Coverings Tested

The descriptions given below of the coverings tested were obtained in most cases from the manufacturer's catalogs, with the exception of the weight and thickness of the coverings, these being obtained from the specimens which were subjected to the tests.

85% Magnesia

This covering is composed of approximately 85 per cent basic carbonate of magnesia and 15 per cent fibrous asbestos, and is used on low- and high-pressure steam lines.

I 1-in. Manufacturer No. 1 85% Magnesia. Thickness, 1.02 in.; weight per 3-ft. section, 5.12 lb. Two sections were tested.

II 2-in. Manufacturer No. 1 85% Magnesia. Thickness, 2.06 in.; weight per 3-ft. section, 12.5 lb. Two sections were tested.

III 3-inch Manufacturer No. 1 85% Magnesia. Thickness, 3.06 in.; weight per 3-ft. section, 22.25 lb. Two sections were tested.

IV 1-in. Manufacturer No. 2 85% Magnesia. Thickness, 1.02 in.; weight per 3-ft. section, 5.2 lb. Five sections were tested.

V 2-in. Manufacturer No. 2 85% Magnesia. Thickness, 2.16 in.; weight per 3-ft. section, 13.25 lb. Two sections were tested.

VI 3-in. Manufacturer No. 2 85% Magnesia. Thickness, 3.52 in.; weight per 3-ft. section, 25.37 lb. Two sections were tested.

VII 1-in. Manufacturer No. 3 85% Magnesia. Thickness, 1.03 in.; weight per 3-ft. section, 4.5 lb. Three sections were tested.

VIII 2-in. Manufacturer No. 3 85% Magnesia. Thickness, 2.07 in.; weight per 3-ft. section, 11.75 lb. Two sections were tested.

IX 3-in. Manufacturer No. 3 85% Magnesia. Thickness, 2.98 in.; weight per 3-ft. section, 18.25 lb. Two sections were tested.

X 1-in. Manufacturer No. 4 85% Magnesia. Thickness, 0.97 in.; weight per 3-ft. section, 5 lb. Two sections were tested.

XI 2-in. Manufacturer No. 4 85% Magnesia. Thickness, 2.08 in.; weight per 3-ft. section, 13 lb. Two sections were tested.

XII 3-in. Manufacturer No. 4 85% Magnesia. Thickness 3.36 in.; weight per 3-ft. section, 25 lb. Two sections were tested.

Nonpareil High-Pressure

This covering is composed of diatomaceous earth (kieselguhr) and asbestos fiber. For use on high-pressure and superheated steam lines.

XIII 1-in. Nonpareil. Thickness, 1.13 in.; weight per 3-ft. section, 6.87 lb. Two sections were tested.

XIV 2-in. Nonpareil. Thickness, 2.09 in.; weight per 3-ft. section, 16 lb. Two sections were tested.

XV 3-in. Nonpareil. Thickness, 3.27 in.; weight per 3-ft. section 30.25 lb. Two sections were tested.

Carey Multi-Ply

This is a laminated type of covering made from indented asbestos paper firmly bound together. For use on medium- and high-pressure steam lines.

XVI 1-in. Carey Multi-Ply. Thickness, 1.05 in.; weight per 3-ft. section, 7.5 lb. Two sections were tested.

XVII 2-in. Carey Multi-Ply. Thickness, 2.04 in.; weight per 3-ft. section 19.5 lb. Four sections were tested.

XVIII 3-in. Carey Multi-Ply. Thickness, 3.01 in.; weight per 3-ft. section, 31.62 lb. Four sections were tested.

Johns-Manville Asbesto-Sponge Felted

This is a laminated type of covering made from felt composed of asbestos fiber and particles of finely ground spongy material. For use on low- or high-pressure steam lines.

XIX 1-in. J. M. Asbestos-Sponge Felted. Thickness, 1.06 in.; weight per 3-ft. section, 9.15 lb. Five sections were tested.

---

[1] Industrial Fellow, Mellon Institute of Industrial Research, University of Pittsburgh. Jun. A.S.M.E.

Contributed by the Power Division and presented at the Spring Meeting, Cleveland, Ohio, May 26 to 29, 1924, of The American Society of Mechanical Engineers. All papers are subject to revision.

XX 2-in. J. M. Asbesto-Sponge Felted. Thickness, 2.08 in.; weight per 3-ft. section, 23 lb. Three sections were tested.

XXI 3-in. J. M. Asbesto-Sponge Felted. Thickness, 3.06 in.; weight per 3-ft. section, 36.58 lb. Three sections were tested.

Carey Hi-Temp.

This covering consists of basic carbonate of magnesia, asbestos fiber, and refractory materials. For use on superheated steam lines up to 1000 deg. fahr.

XXII 1-in. Carey Hi-Temp. Thickness, 1.03 in.; weight, per 3-ft. section, 6.5 lb. Three sections were tested.

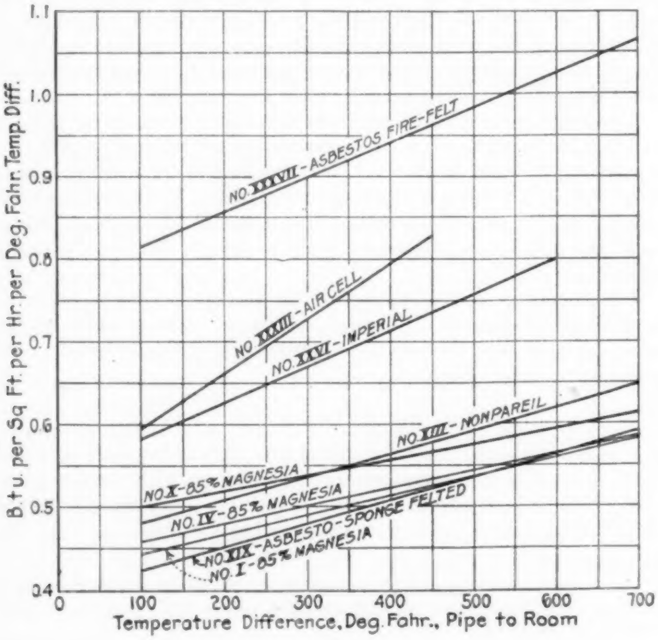


Fig. 1 Tests of Coverings 1 in. Thick

XXIII 1½-in. Carey Hi-Temp. Thickness, 1.53 in.; weight per 3-ft. section, 9.75 lb. Two sections were tested.

XXIV 2-in. Carey Hi-Temp. Thickness, 2.01; weight per 3-ft. section, 13.75 lb. Three sections were tested.

Norristown 2 Point

This is a laminated type of covering consisting of layers of mechanically treated asbestos paper with kieselguhr between the layers. For use on low- and high-pressure steam lines.

XXV 1-in. Norristown 2 Point. Thickness, 1.09 in.; weight per 3-ft. section, 7.41 lb. Three sections were tested.

Watson's Imperial

This is a laminated type of covering consisting of sheets of mechanically treated asbestos paper. For use on low- and high-pressure steam lines.

XXVI 1-in. Imperial. Thickness, 0.92 in.; weight per 3-ft. section, 7.37 lb. Two sections were tested.

Carey Carocel

This covering is composed of alternate layers of plain and corrugated asbestos paper firmly bound together. The corrugations are approximately ⅛-in. deep. For use on medium- and low-pressure steam lines.

XXVII 1-in. Carey Carocel. Thickness, 0.96 in.; weight per 3-ft. section, 7.5 lb. Two sections were tested.

XXVIII 2-in. Carey Carocel. Thickness, 2.02 in.; weight per 3-ft. section, 19 lb. Two sections were tested.

XXIX 3-in. Carey Carocel. Thickness, 2.91 in.; weight per 3-ft. section, 29 lb. Two sections were tested.

Carey Pyrex

This covering is made of successive layers of indented asbestos paper firmly bound together to form an extremely tough, fireproof covering. For use on vibrating high-pressure steam lines.

XXX 1-in. Carey Pyrex. Thickness, 1.00 in.; weight per 3-ft. section, 8.25 lb. Two sections were tested.

XXXI 2-in. Carey Pyrex. Thickness, 1.99 in.; weight per 3-ft. section, 18.25 lb. Two sections were tested.

XXXII 3-in. Carey Pyrex. Thickness, 2.95 in.; weight per 3-ft. section, 33.5 lb. Two sections were tested.

Carey Air Cell

This covering is made of alternate layers of plain and corrugated asbestos paper. The corrugations are approximately ¼-in. deep. For use on medium- and low-pressure steam pipes.

XXXIII 1-in. Carey Air Cell. Thickness, 0.94 in.; weight per 3-ft. section, 3.5 lb. Two sections were tested.

XXXIV 1½ in. Carey Air Cell. Thickness, 1.5 in.; weight per 3-ft. section, 5.37 lb. Two sections were tested.

XXXV 2-in. Carey Air Cell. Thickness, 2.01 in.; weight per 3-ft. section, 7.67 lb. Two sections were tested.

Johns-Manville Asbestocel

This covering is composed of alternate layers of plain and corrugated asbestos felt. The corrugations are approximately ¼ in. deep. For use on medium-pressure steam and hot-water pipes.

XXXVI 1-in. J. M. Asbestocel. Thickness, 1.11 in.; weight per 3-ft. section, 4.44 lb. Four sections were tested.

Johns-Manville Asbestos Fire-Felt

Consists of asbestos fiber loosely felted together and has a strong, hard surface. For use on high-pressure and superheated-steam lines.

XXXVII 1-in. J. M. Asbestos Fire-Felt. Thickness, 1.05 in.; weight per 3-ft. section, 12 lb. Two sections were tested.

XXXVIII 1½ J. M. Asbestos Fire Felt. Thickness, 1.6 in.; weight per 3-ft. section, 19.7 lb. Two sections were tested.

Discussion of Results

Figs. 1 to 7 inclusive, show the results of tests on 15 different brands of coverings in thicknesses of 1 in. to 3 in., inclusive.

The curves show the heat loss in B.t.u. per hr. per sq. ft. of pipe surface per deg. fahr. temperature difference between pipe surface

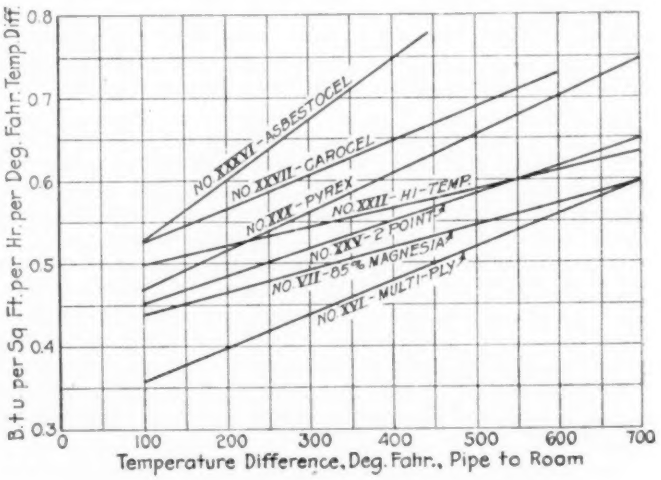


Fig. 2 Tests of Coverings 1 in. Thick

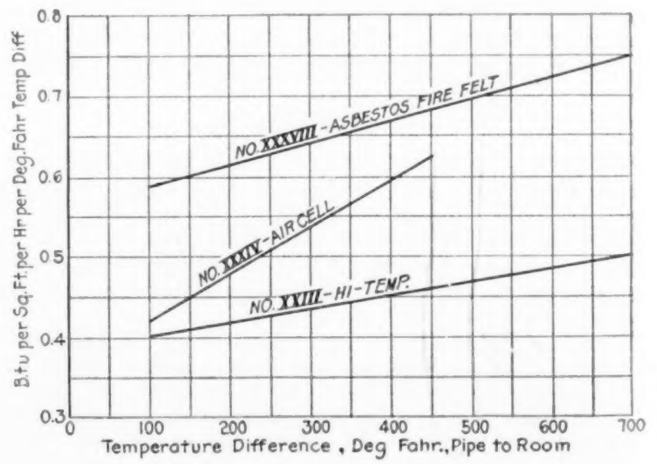


Fig. 3 Tests of Coverings 1½ in. Thick

and room. Upon examination it will be found that these curves are all represented as straight lines. Some former investigations have indicated the heat-loss curves for similar materials as curved lines rather than straight lines. The curvature of these lines may have been caused by inability to hold the power supplied to the heating coils absolutely constant and by not allowing sufficient time for the heat flow to become constant, and perhaps by inaccuracies in the taking of the test data. It was found during this investigation that some of the points on the heat-loss curve would deviate somewhat from a straight line if great care was not exercised in keeping the power supply constant and in allowing the heat flow to become steady before final readings were taken. Since the heat-loss curves are plotted to 0.001 B.t.u., it will readily be seen that a slight error

in any of the variables mentioned above will cause an appreciable error in the plotting of the curves

In Figs. 1 to 7, inclusive, are shown 38 heat-loss curves, which represent the results of 92 tests on pipe coverings. It was deemed inadvisable to include the curve for each test as this would require considerable space, so that the average curve for each thickness of material tested only is given.

The average curve for each thickness was determined from the results of all the tests conducted from each type of covering having approximately the same thickness, and the true thickness of each type of covering tested was taken from the average thickness of all the coverings of that type tested having approximately the same thickness.

Meaning of Term "Thermal Conductivity"

The term "thermal conductivity" has been rather loosely used in the last few years by investigators and in engineering literature. This lack of correct definition has therefore caused considerable misrepresentation on the part of certain investigators as to the true conductivity values of insulating materials reported by them. In fact, there are practically no reports in engineering literature which present the true conductivity values of pipe-covering materials tested so that they may be applied in determining the heat loss for

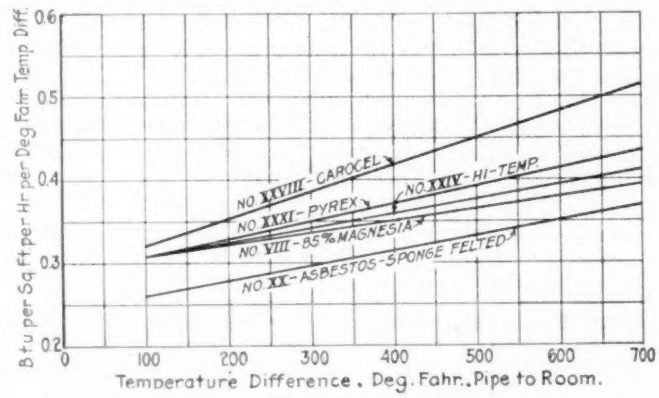


FIG. 4 TESTS OF COVERINGS 2 IN. THICK

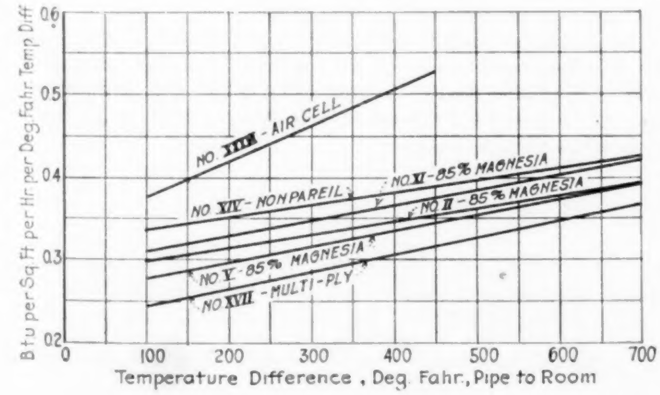


FIG. 5 TESTS OF COVERINGS 2 IN. THICK

conditions not exactly similar to the test conditions under which the constants were determined.

The true meaning of the term "thermal conductivity" of a material is the number of heat units transferred by conduction per unit area, across unit thickness, per degree difference of temperature between the faces, the direction of heat flow being perpendicular to these faces. In terms of the units generally used in power-plant practice this is equivalent to the heat transmitted in B.t.u. per hr. through 1 sq. ft. of material 1 in. thick and having 1 deg. fahr. temperature difference between its faces.

It is practically impossible to realize a condition in engineering or laboratory practice where the temperature difference between two faces one inch apart is only one degree, and the conductivity of an insulating material has therefore generally been taken as the average conductivity value through the whole test section; the conductivity thus obtained being plotted against the temperature difference between the two surfaces or between the inner surface and the room temperature. Plotting average conductivity against temperature difference at the two surfaces for heat-insulating materials may give in some cases where single thicknesses are used solutions sufficiently accurate for engineering purposes, but where compound sections are employed and where different external surfaces exist as in coverings on various-diameter pipes—with a resulting change in the surface-emissivity factor—it is not safe at all to use the values obtained from conductivity curves plotted against temperature differences.

For example, it is a well-known fact that the conductivity of

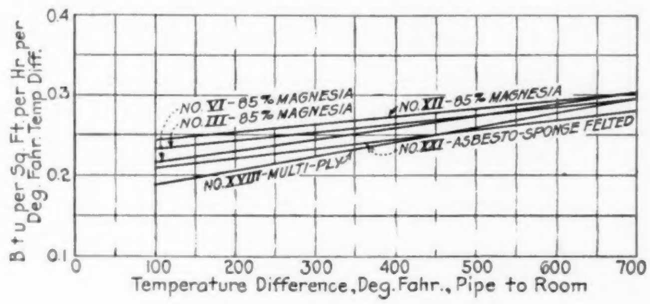


FIG. 6 TESTS OF COVERINGS 3 IN. THICK

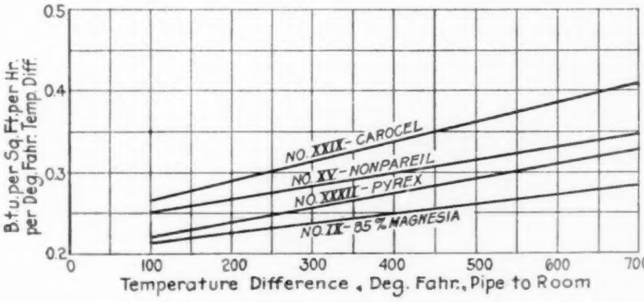


FIG. 7 TESTS OF COVERINGS 3 IN. THICK

heat-insulating materials increases as the temperature increases. The conductivity value of a given material whose faces are at 200 and 100 deg. fahr. must therefore be lower than the conductivity for the same material having its faces at 700 and 600 deg. fahr., although the temperature differences is 100 deg. in each case. From the results of tests presented in this paper it can readily be seen that an error as great as 100 per cent can easily be made by calculating the loss through a material such as air cell from a conductivity curve plotted against temperature difference.

Carl Hering[1] has proved mathematically that when the conductivity of an insulating material is proportional to the absolute temperature, the equivalent conductivity for the whole thickness of the insulation is equal to the conductivity corresponding to the arithmetical mean of the two surface temperatures. In order that the proposition may be true, as brought out by Richards and Barrett, it is unnecessary that the conductivity be proportional to the absolute temperature as was assumed by Hering, but only that it be a linear function of the temperature such as $K = aT + b$, where K is conductivity, T the temperature, and a and b are constants.

In all the tests on commercial insulating coverings conducted during this investigation there was no covering tested whose conductivity did not obey a straight-line law. This fact reduces considerably the experimental work required to obtain true conductivity values for the insulating materials tested, as it is only necessary to measure the heat transmitted through the covering and the corresponding surface temperature.

However, as a further proof that the above law can safely be used to determine the thermal conductivity at various temperatures, an experiment was conducted on one brand of covering in order to check the true thermal conductivity of a covering as obtained by means of a temperature-gradient curve against the equivalent conductivity on the same covering as obtained from the heat loss through the covering at a given mean temperature.

[1] Trans. Am. Electrochem. Soc., vol. xxi, p. 520.

Thermal Conductivity of Covering from Temperature-Gradient Curve

From the relation that the flow of heat H through unit area per unit of time is equal to the conductivity K multiplied by the temperature gradient, or $H = K\frac{dt}{dx}$, it is possible to determine the true conductivity of an insulating material from its temperature-gradient curve and the flow of heat through it.

Several methods of determining the temperature gradient through a covering have been tried in this investigation, but the best method proved to be that of inserting small thermocouples between each layer of a laminated type of covering and then placing the covering on the test pipe and running a conductivity test in the regular manner, taking temperature readings on each of the small thermocouples after the heat flow has reached a steady state.

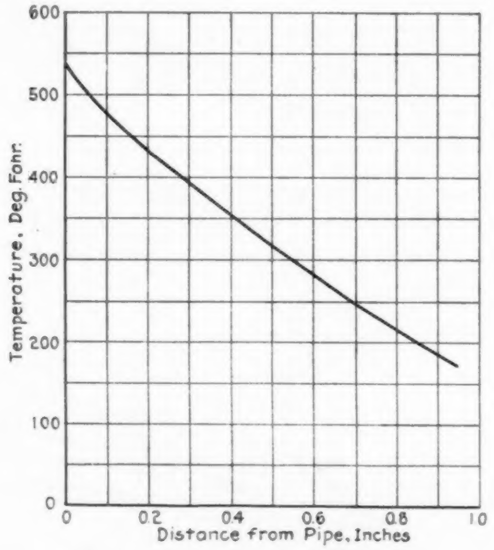


Fig. 8 Temperature-Gradient Curve

Fig. 8 shows the temperature-gradient curve taken on Watson's Imperial covering having 22 plies or sheets of asbestos paper. This covering was chosen for the temperature gradient test on account of the ease and fair degree of accuracy with which the thermocouples could be placed. Eighteen couples were inserted between the sheets of paper and the temperatures obtained were plotted against the distance of the couples from the pipe and a smooth curve drawn through the points obtained. The covering on which the temperature gradient was measured was 0.96 in. thick.

The heat loss through the covering at the time the temperature gradient was measured was 335.5 B.t.u. per sq. ft. of inner surface per hr. The pipe temperature was 541 deg. fahr. and the temperature of the outer surface of the covering was 175 deg. fahr. the mean temperature was thus 358 deg. fahr.

The equivalent conductivity at 358 deg. mean temperature and 366 deg. temperature difference between inner and outer surface was equal to

$$\frac{335.5 \times 1.75 \log_e \frac{2.71}{1.75}}{366} = 0.702 \text{ B.t.u.}$$

The true thermal conductivity at 358 deg. fahr. was determined from the temperature-gradient curve by two methods. The first method, which is probably the most accurate, is to derive an equation for the temperature-gradient curve and from this equation determine the slope of the curve and substitute the value so obtained in the general equation; while the second method is to obtain the slope of the curve by drawing a tangent to the curve at the 358-deg. point.

The temperature gradient curve can be fairly accurately expressed by the equation

$$t^2 + at + bx + c = 0$$

in which t and x are the variables temperature and distance, respectively, and a, b, and c are constants. The constants were determined in this case by taking three sets of values for t and x, substituting these in the general equation for the temperature-gradient curve, and solving the three simultaneous equations for a, b, and c. The temperatures corresponding to the distances 0.3 in., 0.4 in., and 0.6 in. or 395 deg., 355 deg., and 282 deg., respectively, were substituted in the equation.

These distances were chosen fairly close to the distance corresponding to 358 deg. as the temperature-gradient curve obtained was somewhat more sharply curved at the upper and lower ends than in the central portion. The values obtained for a, b, and c at the points chosen are

$$a = -1930,\ b = -473{,}000, \text{ and } c = 748{,}600$$

From the temperature-gradient curve it is noted that the distance from the pipe corresponding to 358 deg. is 0.39 in. The heat loss in B.t.u. per sq. ft. is then equal to

$$\frac{335.5 \times 1.75}{1.75 + .39} = 274$$

since the covering was tested on a 3-in. standard steel pipe.

Now $K = \frac{H}{(dt/dx)}$, or the conductivity K at 358 deg. is equal to the heat loss divided by the slope of the temperature-gradient curve at 358 deg.

The slope of the temperature-gradient curve is found by differentiating the equation of that curve and obtaining the first derivative. Differentiation of the equation $t^2 + at + bx + c = 0$ gives $2tdt + adt + bdx = 0$. The derivative is

$$\frac{dt}{dx} = \frac{-b}{2t + a}$$

Substituting the value for $\frac{dt}{dx}$ in the equation $K = \frac{H}{dt/dx}$ gives

$$K = H\frac{2t + a}{-b}$$

in which K = conductivity at temperature t.

The conductivity at any temperature can be obtained by means of this equation, the accuracy of the conductivity value obtained depending of course on the accuracy with which the temperature-gradient curve and corresponding data have been taken. The conductivity at 358 deg. is then

$$K = 274\,\frac{(716 - 1930)}{473{,}000} = 0.704 \text{ B.t.u.}$$

The conductivity at 358 deg. was also obtained by the tangent method which is much simpler than the previous method described. By this method the length of the subtangent at 358 deg. = 1.31 — 0.39 = 0.92, from which $\frac{dt}{dx} = \frac{358}{0.92} = 389$. The heat loss per sq. ft. at 0.39 in. from the surface of the pipe = 274 B.t.u.

$$\therefore K \text{ at 358 deg. fahr.} = \frac{274}{389} = 0.705 \text{ B.t.u.}$$

per hr. per sq. ft. per in. per deg. fahr. temperature difference.

The values 0.704 and 0.705 obtained from the temperature-gradient curve check very closely with the value 0.702 obtained as the equivalent conductivity.

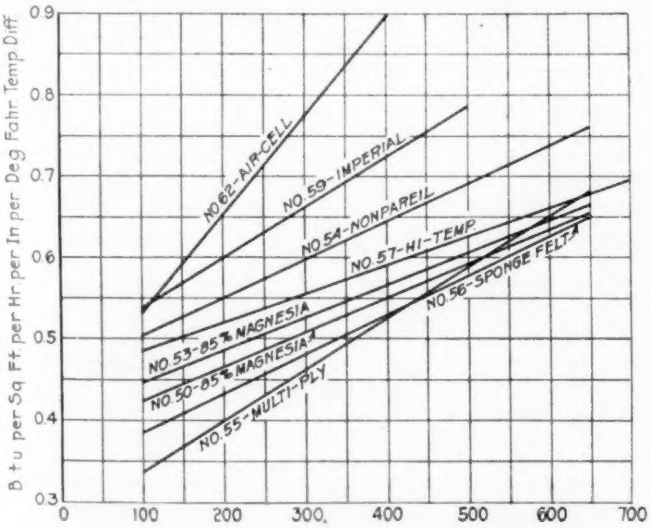
It has therefore been concluded that it is perfectly safe to use the equivalent conductivity values obtained in this investigation as the true value of thermal conductivity for the coverings tested. In fact, the author is of the opinion that the conductivity values obtained by taking the conductivity at the mean of the two surface temperatures in all the coverings tested are much more accurate than those obtained from temperature-gradient curves, as it is very difficult to obtain true temperature-gradient curves for any insulating material on a cylindrical test pipe.

If the equation given for determining the conductivity from the temperature-gradient curve is applied to either the upper or lower end of temperature-gradient curve Fig. 8, it will be found that the values obtained will differ somewhat from the values which would be expected. This is probably due to the conditions which affect the accuracy in the temperature and distance measurements, and to the fact that a slight error in drawing in the curve at these points causes a considerable variation in the slope obtained.

A great many temperature-gradient curves for different materials were obtained and it was noted in every case that the conductivity values calculated from the central portion of the curve was fairly accurate, while the values obtained from the ends of the curves were considerably in error.

The curves shown in Fig. 9 and 10 were obtained by calculating the conductivity of the coverings tested and plotting the conductivity values obtained against the mean of the two surface temperatures.

Where more than one thickness of a given brand of covering was tested the conductivity for the average of all the coverings of a given thickness and the average of the conductivity curves for all thicknesses tested was taken as the true conductivity of the material. For instance, in the case of Nonpareil covering where 1-in., 2-in., and 3-in. thicknesses were tested, conductivity curves were calculated for the 1-in., the 2-in., and the 3-in. thicknesses and the average of these three curves was taken as the true conductivity curve for Nonpareil. This method was followed for all the coverings tested with the exception of Asbestos Fire-Felt. In this case two separate conductivity curves are given, one for material 1-in. thick and the other for $1^1/_2$-in. material. The construction



Mean Temperature, Deg. Fahr. between Inner and Outer Surfaces

Fig. 9 Curves of Thermal Conductivity

of Asbestos Fire-Felt is such that a greater proportion of hard and consequently better conducting material is contained in the covering 1-in. thick than in the $1^1/_2$-in. covering which results in the thermal-conductivity curve for the material 1-in. thick being higher than the curve for the $1^1/_2$-in. material.

The outer surface temperatures of all the coverings tested were measured with thermocouples. The temperatures obtained were compared with the equation[1]

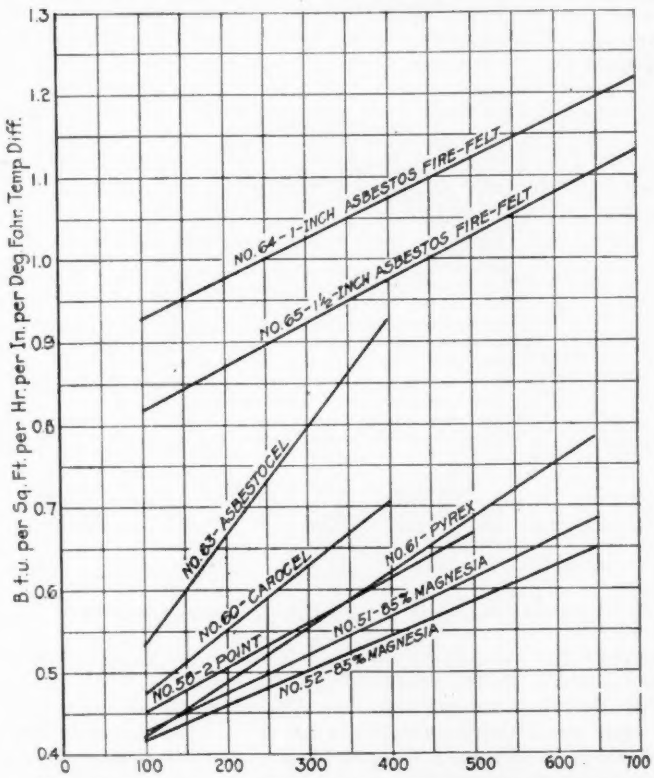
$$T_d = \frac{272.5\,h}{h + \dfrac{564}{D^{0.19}}}$$

and in practically every case it was found that the equation gave the true surface temperature within less than 1 deg. fahr.

It was decided to use the above equation in calculating the thermal conductivity of the coverings tested as this method simplified the calculations considerably. In view of the fact that the actual surface temperatures obtained checked so closely with those obtained from the equation, the error introduced by this method can be considered as negligible. These curves are shown in Fig. 9 and Fig. 10.

The thermal-conductivity curves for the following materials are included in Fig. 9 and Fig. 10.

No. 50 Manufacturer No. 1 85% Magnesia. Average of 6 tests.
No. 51 Manufacturer No. 2 85% Magnesia. Average of 9 tests.
No. 52 Manufacturer No. 3 85% Magnesia. Average of 7 tests.
No. 53 Manufacturer No. 4 85% Magnesia. Average of 6 tests.
No. 54 Nonpareil. Average of 6 tests.
No. 55 Carey Multi-Ply. Average of 8 tests.
No. 56 Johns-Manville Asbesto-Sponge Felted. Average of 11 tests.



Mean Temperature, Deg. Fahr. between Inner and Outer Surfaces

Fig. 10 Curves of Thermal Conductivity

No. 57 Carey Hi-Temp. Average of 7 tests.
No. 58 Norristown 2 Point. Average of 3 tests.
No. 59 Watson Imperial. Average of 2 tests.
No. 60 Carey Carocel. Average of 6 tests.
No. 61 Carey Pyrex. Average of 6 tests.
No. 62 Carey Air Cell. Average of 9 tests.
No. 63 Johns-Manville Asbestocel. Average of 4 tests.
No. 64 Johns-Manville Asbestos Fire-Felt. 1 in. Thick. Average of 2 tests.
No. 65 Johns-Manville Asbestos Fire-Felt. $1^1/_2$ in. Thick. Average of 2 tests.

Heat-Insulating Cements

The apparatus shown in Fig. 11 which is used in testing heat-insulating cements consists of a cast-iron ball 12.15 in. in diameter and $^1/_4$ in. thick, inside of which is centered an alundum ball $^1/_2$ in. thick whose outer surface at all points is $^3/_{16}$ in. from the inner surface of the iron ball. The alundum ball is grooved for a heating coil of resistance wire which is spaced so as to give a uniform distribution of heat over the entire surface of the ball. Since the surface of the iron ball is in the form of a uniform sphere, it is unnecessary to have any guard-ring coils to take care of end losses as is required in the cylindrical testing apparatus.

The temperature of the outer surface of the iron ball or the temperature of the insulating cement applied to the surface of the ball is measured by 6 thermocouples uniformly spaced around the circumference of the ball in a vertical plane. These thermocouples are peened into the surface of the iron in the same manner as those in the cylindrical test pipes.

The cement to be tested is applied to the surface of the iron ball with a trowel and the uniformity of the thickness of cement applied is determined by means of templets. The actual thickness of the

[1] Trans. A.S.M.E., vol. 44 (1922), p. 309.

cement applied is determined by 10 measurements of the circumference over the cement.

The temperature of the outer surface of the cement is measured with 4 thermocouples uniformly spaced around the circumference, the thermocouples being held to the surface of the cement by gummed labels $1^9/_{16}$ in. by $3^{13}/_{16}$ in. in size.

The most important points to be noted when testing insulating cements are insulating value, covering capacity, sticking qualities, shrinkage, and cracking.

The insulating value is obtained from the heat loss through the cement, and the temperature at the two surfaces and the room temperature. The covering capacity is obtained approximately by weighing the amount of cement removed from the apparatus after

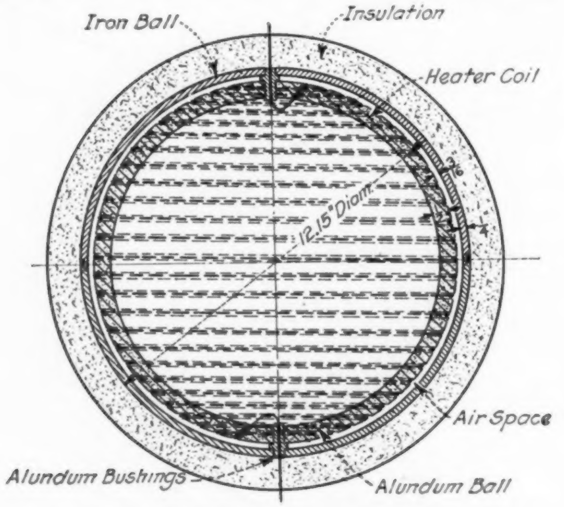


Fig. 11 Apparatus for Testing Insulating Cements

the test is finished. The sticking qualities, shrinkage, and cracking can be determined from personal observation.

The heat loss through 1-in.-thick 85% Magnesia cement and its thermal conductivity are shown in Fig. 12. The cement tested was 1.03 in. thick and had a covering capacity of approximately 60 sq. ft. (1 in. thick) per 100 lb.

The results of only one test on insulating cements will be given at this time as the tests on cements have just been commenced and the author expects to give the results of tests on the most important insulating cements as an appendix to this paper.

The heat loss through an insulation applied to the surface of a sphere in B.t.u. per sq. ft. of inner surface of the insulation per hr. is given by the equation:

$$H = \frac{K(t_1 - t_2)r_2}{(r_2 - r_1)r_1} \qquad [1]$$

whence

$$K = \frac{H(r_2 - r_1)r_1}{(t_1 - t_2)r_2} \qquad [2]$$

The equivalent conductivity of the insulation was determined from Equation [2] by calculating the value of K for various test values of t_1 and t_2 and plotting K against the temperature at the mean of the two surface temperatures.

The heat loss through 2.94 in. thickness of Sil-O-Cel brick or "soaps" and Sil-O-Cel powder on a 10-in. pipe and the thermal conductivity of the same are also included in Fig. 12. The "soaps" which measured approximately $2^1/_2 \times 2^3/_8 \times 9$ in., were wired to a 10-in. pipe-covering tester and all cracks were cemented with Sil-O-Cel powder mixed with water, after which the entire outer surface of the soaps was covered with about $^1/_4$ in. thickness of the powder and water. A canvas jacket was then applied and the test run in the same manner as for the 3-in. pipe coverings. Owing to the fact that considerable powder had to be used in this test and that the blocks did not fit snugly to the test pipe it is to be understood that the results obtained give only approximately the values for Sil-O-Cel brick, and the curves are therefore only included for what value they may contain.

Calculation of Heat Losses Through Coverings

The theoretical calculation of heat losses through coverings on flat and curved surfaces is somewhat difficult, due to the fact that the emissivity factors for various surfaces are not the same. This fact causes a variation in the surface temperatures for a given rate of loss. In order to determine the heat loss through the material it is necessary to know the temperatures at the inner and outer surface and the conductivity of the material at the mean temperature between the two surfaces. Probably the simplest process of calculating the loss through a covering is to make an assumption of the outer-surface temperature, and then from the conductivity curve determine the conductivity of the material at the mean of the surface temperature assumed and the inner-surface temperature.

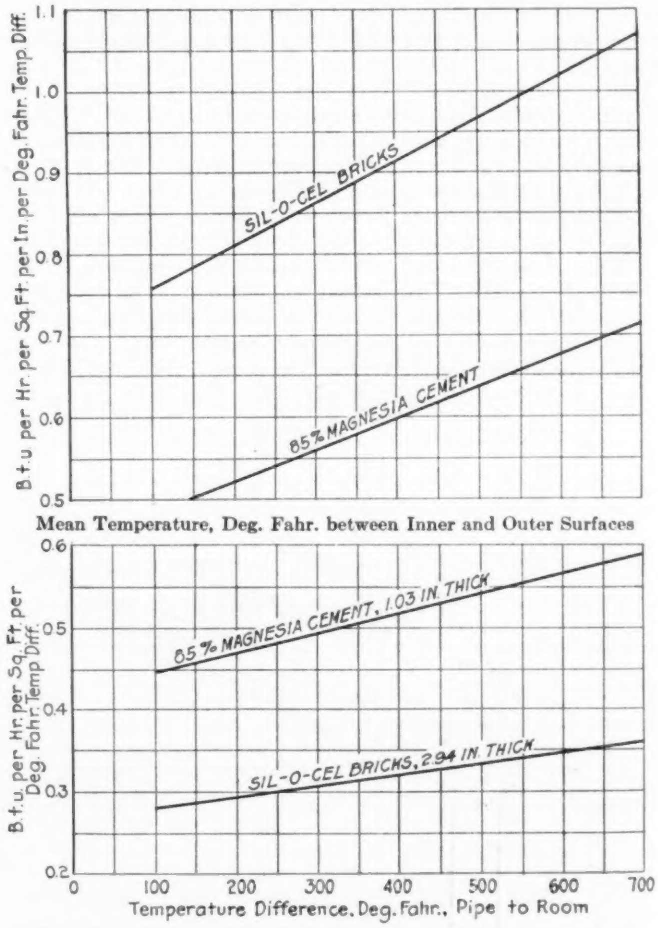


Fig. 12 Thermal Conductivity (Upper Chart); Test Results (Lower Chart)

The loss through the covering should then be calculated for the assumed outer-surface temperature and this loss should be checked against the loss as obtained from the surface-loss curve or equation. If the two losses do not check the assumed outer-surface temperature must be changed according to the indications of the calculation and the process repeated until the two losses or the outer-surface temperatures check. At first this may seem to be a very tedious method, but with the aid of the curves and tables included in this paper one will find that the loss through single and compound sections can be accurately calculated in a very short time.

In the case of a flat surface the quantity of heat conducted per unit of area and time is given by the equation

$$H = K(T_1 - T_3 - T_d)$$

in which

H = B.t.u. loss per hr. per sq. ft. of surface
K = thermal conductivity of insulation
T_1 = temperature of inner surface of insulation
T_3 = temperature of room
T_d = temperature difference between outer surface of insulation and room
X = thickness of insulation

This equation can be changed to

$$H = \frac{K(T_1 - T_2)}{X}$$

in which T_2 = outer surface temperature, since $T_2 = T_3 + T_d$.

As mentioned above, the main difficulty in solving this equation is due to the uncertainty of the outer-surface temperature as in most cases the only temperatures known are the steam temperature and the room temperature.

Various investigators have studied the heat losses from flat and curved surfaces but none have been able to satisfactorily equate the loss from a flat surface, since the loss of heat per unit area from flat surfaces varies greatly with the size and position of the body. The loss from the surface in a horizontal position is entirely different from that for the same surface in a vertical position. Also, the loss is different for the same flat surface facing downward from that when facing upward.

However, the author has carefully investigated the surface losses from various-diameter canvas-covered pipe insulations the results of which can be expressed by the equations

$$T_d = \frac{272.5h}{h + \frac{564}{D^{0.19}}}$$

or

$$h = \frac{564\,T_d}{D^{0.19}(272.5 - T_d)}$$

The loss from a flat surface cannot be expressed from these equations, but to enable one to arrive at an approximate flat-surface temperature it is suggested that the equations be used, assuming D to be a 30-in. pipe, when

$$T_d = \frac{272.5h}{h + 295} \quad \text{or} \quad h = \frac{295\,T_d}{272.5 - T_d}$$

It is to be understood that this will give only approximate results for flat surfaces and is not based on any flat-surface loss determinations by the author but is only suggested until something more definite is developed.

In the case of a cylindrical surface having a single section of insulation applied, the quantity of heat conducted per unit of area and time is given by the equation

$$H = \frac{K(T_1 - T_2)}{r_1 \log_e\left(\frac{r_2}{r_1}\right)}$$

However, it is more convenient to work from the outer surface of the insulation since the loss through the covering must be checked from the loss from the outer surface. In the case of a flat surface, the loss per unit area is the same for the inner and outer surfaces, while the loss per unit area from a cylindrical surface is greater for the inner surface than for the outer surface, or $H = h(r_2/r_1)$. Therefore

$$h = \frac{K(T_1 - T_2)}{r_2 \log_e\left(\frac{r_2}{r_1}\right)}$$

in which h = B.t.u. loss per hr. per sq. ft. of outer surface.

The process involved will be illustrated by an example. Determine the heat flow in B.t.u. per hour per sq. ft. of pipe surface through an air-cell covering 1 in. thick on a 4-in. pipe. The temperature of the pipe is 370 deg. fahr. and the room temperature, 70 deg. fahr.

From Table 4 the approximate canvas temperature difference at 300 deg. temperature difference pipe to room for a 1-in. thick covering on a 4-in. pipe is 69 deg. The mean temperature of the covering is then equal to (370 + 139)/2 or 254.9 deg. From curve No. 62, Fig. 9, the conductivity of air cell at 254.9 deg. is found to be 0.717. The value of $r_2 \log_e(r_2/r_1)$ is found in Table 1 to be 1.19 and the temperature difference between the inner and outer surface covering = 370 — 139 = 231 deg., making

$$h = \frac{0.717 \times 231}{1.19} = 139 \text{ B.t.u.}$$

This value is substituted in the surface-loss equation as follows:

$$T_d = \frac{272.5 \times 139}{139 + \frac{564}{7.5^{0.19}}}$$

from Table 2, $564/7.5^{0.19} = 385$, whence

$$T_d = \frac{272.5 \times 139}{139 + 385} = 72.3 \text{ deg. fahr.}$$

It will generally be found that the correct surface temperature will be very near the first temperature calculated from the surface-loss equation, as a variation of several degrees in the surface temperature will cause only a slight variation in the conductivity value.

Next, a surface temperature of 142 deg. is assumed. The mean temperature = 256 deg. and the conductivity = 0.72 B.t.u. while the temperature difference between the inner and outer surface = 228 deg.

$$h = \frac{0.72 \times 228}{1.19} = 138 \text{ B.t.u.}$$

Checking again,

$$T_d = \frac{272.5 \times 138}{138 + 385} = 72 \text{ deg.}$$

This indicates that 138 B.t.u. is the correct loss per square foot of outer surface. The loss per square foot of pipe surface is then $138 \times \frac{3.25}{2.25} = 199$ B.t.u. per hr. per sq. ft.

This method of calculating gives results which are strictly accurate and it is believed that with the use of the curves and tables included—which can be interpolated for conditions varying between those given in the tables—all persons interested in working out heat problems will find a ready means of solving them in this section of the report.

In most cases where extreme accuracy is not necessary the loss of heat through any of the insulations tested in this investigation for any thickness of covering and for any temperatures generally used in engineering practice can be obtained from Table 5 and Figs. 13 to 17, inclusive.

In these curves the unit loss through 1, $1^1/_2$, 2, 3 and 4-in. thick Multi-Ply is given for temperature differences up to 700 deg. fahr.

The loss through other thicknesses can be obtained from the curves by interpolation and the loss at somewhat higher temperatures can be obtained by extending the curves.

Table 5 gives the factor by which the loss through Multi-Ply covering must be multiplied to give the loss through any of the coverings tested.

For example, the loss through the air-cell installation previously solved can be obtained from Fig. 13 and Table 5 very readily as follows: The loss through Multi-Ply covering 1-in. thick on 4-in. pipe at 300 deg. temperature difference = 0.431; the factor for air cell at 300 deg. temperature difference = 1.58; then the heat loss through the air cell = 0.431 × 1.58 × 300 = 204 B.t.u. per sq. ft. of pipe surface per hr. This value checks very closely with the value of 199 previously obtained, and for most engineering purposes the values obtained by the last method will be sufficiently accurate.

Table 3 gives the approximate canvas temperature difference between canvas and room for the best-grade coverings, such as Multi-Ply, Asbesto-Sponge and Magnesia, while Table 4 gives the approximate canvas temperature difference for medium-grade coverings such as Air Cell and Asbestocel. The approximate canvas temperature difference for other types of coverings can be obtained by interpolation from Tables 3 and 4 and the thermal-conductivity curves in Figs. 9 and 10.

These tables are based on a room temperature of 70 to 80 deg. fahr. Unless the room temperature varies considerably from 70 to

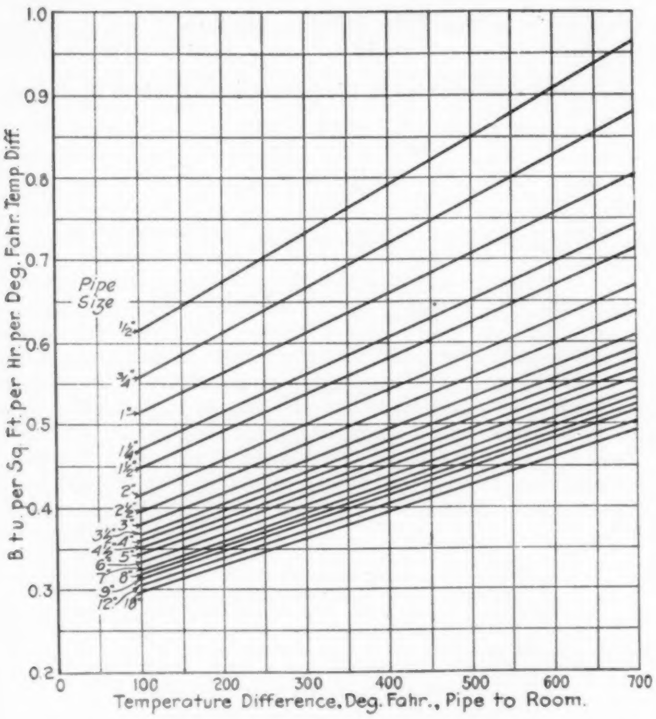


FIG. 13 HEAT LOSS THROUGH MULTI-PLY COVERINGS 1 IN. THICK

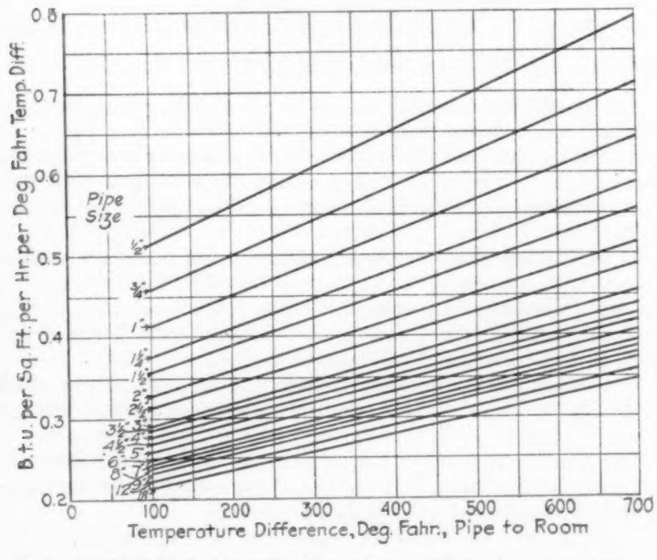


FIG. 14 HEAT LOSS THROUGH MULTI-PLY COVERING 1 1/2 IN. THICK

80 deg. fahr. it will be unnecessary to change the values given in these tables.

The determination of heat transmission through compound sections is somewhat more difficult than the calculation for single sections, the labor involved in making the calculations increasing as the number of sections is increased.

The equation for compound sections on a flat surface is

$$H = \frac{T_1 - T_2}{\dfrac{X_1}{K_1} + \dfrac{X_2}{K_2} + \dfrac{X_3}{K_3} +} \quad \ldots\ldots\ldots\ldots [3]$$

while the corresponding equation for cylindrical surfaces is

$$H = \frac{T_1 - T_2}{\dfrac{r_1 \log_e \frac{r_2}{r_1}}{K_1} + \dfrac{r_1 \log_e \frac{r_3}{r_2}}{K_2} + \dfrac{r_1 \log_e \frac{r_4}{r_3}}{K_3} +} \quad \ldots\ldots\ldots [4]$$

or in terms of the heat loss per sq. ft. of outer surface,

$$h = \frac{T_1 - T_2}{\dfrac{r_s \log_e \frac{r_2}{r_1}}{K_1} + \dfrac{r_s \log_e \frac{r_3}{r_2}}{K_2} + \dfrac{r_s \log_e \frac{r_4}{r_3}}{K_3} +} \quad \ldots\ldots\ldots [5]$$

The practical value of these equations is probably best illustrated by the fact that when insulating high-temperature pipe lines in the past it has been common practice to use a first layer of matted asbestos, held in shape by a silicate-of-soda shell (Fiber Felted Blocks or Fire Felt) over which better insulators such as Multi-Ply, Sponge Felt, or Magnesia are applied. The first layer, composed of a material capable of withstanding high temperatures, is supposed to reduce the temperature to which the outer layer is subjected to within its proper working range, but due to the poor insulating value of this class of material many standard specifications, which were arrived at by rule of thumb, do not use a sufficient thickness of high-temperature insulation to accomplish this purpose. The following analysis of a section that has been largely used when temperatures of 750 deg. fahr. prevail will demonstrate the value of computing intermediate temperatures in any section considered, by some such method as that outlined in the following paragraphs.

Conditions: Six-inch pipe at a temperature of 750 deg. fahr., covered with a 1-in. thick layer of matted asbestos insulation, over which is applied a 2-in.-thick layer of either Asbestos Covering or 85% Magnesia, the room or air temperature being 70 deg. fahr. By computing intermediate temperatures, as outlined below, it is found that when 85% Magnesia is used as an outer covering its initial temperature is 606 deg. fahr. and that when the best asbestos coverings such as Multi-Ply or Sponge Felt are used, the initial temperature for these materials goes to 608 deg. fahr. Some

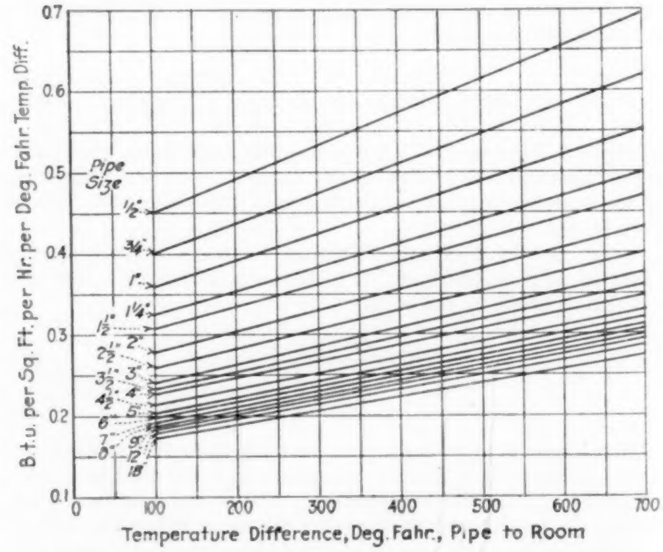


FIG. 15 HEAT LOSS THROUGH MULTI-PLY COVERING 2 IN. THICK

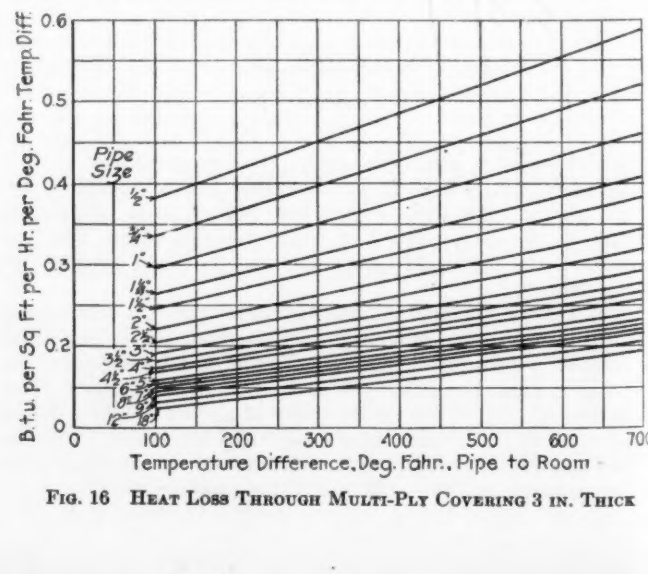


FIG. 16 HEAT LOSS THROUGH MULTI-PLY COVERING 3 IN. THICK

TABLE 1 VALUES OF $r_2 \log_e (r_2/r_1)$ FOR COVERINGS OF VARIOUS THICKNESSES ON DIFFERENT-SIZED PIPES

		Thickness of Covering											
		1 in.		1 1/2 in.		2 in.		2 1/2 in.		3 in.		4 in.	
Pipe size, in.	r_1	r_2	$r_2 \log_e \frac{r_2}{r_1}$	r_2	$r_2 \log_e \frac{r_2}{r_1}$	r_2	$r_2 \log_e \frac{r_2}{r_1}$	r_2	$r_2 \log_e \frac{r_2}{r_1}$	r_2	$r_2 \log_e \frac{r_2}{r_1}$	r_2	$r_2 \log_e \frac{r_2}{r_1}$
1/2	0.420	1.420	1.730	1.920	2.920	2.420	4.235	2.920	5.660	3.420	7.165	4.420	10.400
3/4	0.525	1.525	1.625	2.025	2.733	2.525	3.965	3.025	5.294	3.525	6.710	4.525	9.760
1	0.657	1.657	1.532	2.157	2.563	2.657	3.710	3.157	4.950	3.657	6.278	4.657	9.110
1 1/4	0.830	1.830	1.448	2.330	2.402	2.830	3.470	3.330	4.622	3.830	5.855	4.830	8.500
1 1/2	0.950	1.950	1.400	2.450	2.322	2.950	3.340	3.450	4.445	3.950	5.620	4.950	8,170
2	1.187	2.187	1.335	2.687	2.194	3.187	3.145	3.687	4.177	4.187	5.262	5.187	7.658
2 1/2	1.437	2.437	1.288	2.937	2.062	3.437	2.996	3.937	3.965	4.437	5.000	5.437	7.230
3	1.750	2.750	1.240	3.250	2.010	3.750	2.856	4.250	3.770	4.750	4.740	5.750	6.840
3 1/2	2.000	3.000	1.216	3.500	1.959	4.000	2.770	4.500	3.647	5.000	4.580	6.000	6.590
4	2.250	3.250	1.190	3.750	1.913	4.250	2.700	4.750	3.598	5.250	4.450	6.250	6.385
4 1/2	2.500	3.500	1.177	4.000	1.880	4.500	2.640	5.000	3.465	5.500	4.340	6.500	6.210
5	2.781	3.781	1.161	4.281	1.845	4.781	2.588	5.281	3.383	5.781	4.226	6.781	6.043
6	3.312	4.312	1.138	4.812	1.795	5.312	2.507	5.812	3.266	6.312	4.071	7.312	5.790
7	3.812	4.812	1.117	5.312	1.761	5.812	2.448	6.312	3.190	6.812	3.955	7.812	5.626
8	4.312	5.312	1.101	5.812	1.732	6.312	2.405	6.812	3.114	7.312	3.860	8.312	5.450
9	4.812	5.812	1.109	6.312	1.710	6.812	2.370	7.312	3.060	7.812	3.790	8.812	5.335
10	5.375	6.375	1.085	6.875	1.694	7.375	2.334	7.875	3.007	8.375	3.707	9.375	5.220
12	6.370	7.375	1.073	7.875	1.660	8.375	2.285	8.875	2.932	9.375	3.614	10.375	5.060
14	7.000	8.000	1.067	8.500	1.654	9.000	2.262	9.500	2.900	10.000	3.566	11.000	4.986
16	8.000	9.000	1.059	9.500	1.630	10.000	2.236	10.500	2.852	11.000	3.500	12.000	4.860
18	9.000	10.000	1.048	10.500	1.620	11.000	2.203	11.500	2.817	12.000	3.455	13.000	4.795

TABLE 2 VALUES OF $\frac{564}{D^{0.19}}$

(*D* in inches)

D	$\frac{564}{D^{0.19}}$	D	$\frac{564}{D^{0.19}}$	D	$\frac{564}{D^{0.19}}$	D	$\frac{564}{D^{0.19}}$
3.00	458	6.0	401	10.5	361	17.0	329
3.25	451	6.5	395	11.0	357	18.0	325
3.50	445	7.0	390	11.5	354	19.0	322
3.75	439	7.5	385	12.0	351	20.0	319
4.00	433	8.0	380	12.5	349	21.0	316
4.25	428	8.5	375	13.0	346	22.0	313
4.50	423	9.0	371	14.0	341	23.0	310
5.0	415	9.5	367	15.0	337	24.0	308
5.5	408	10.0	364	16.0	333		

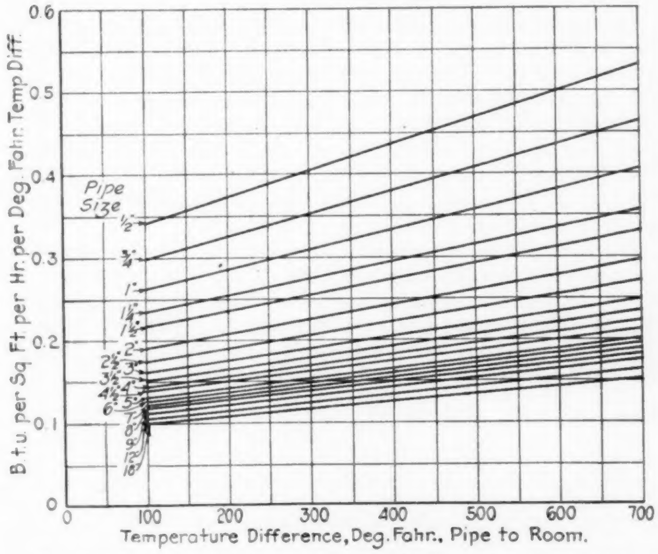


Fig. 17 Heat Loss Through Multi-Ply Covering 4 in. Thick

TABLE 5 PIPE-COVERING FACTORS

Type of Covering	Temperature Difference, Pipe to Air, Deg. Fahr. 100	200	300	400	500	600	700
	Factor						
Mfr. No. 1 85% Magnesia	1.207	1.163	1.133	1.100	1.075	1.045	1.025
Mfr. No. 2 85% Magnesia	1.245	1.195	1.164	1.132	1.105	1.082	1.060
Mfr. No. 3 85% Magnesia	1.200	1.160	1.127	1.090	1.068	1.040	1.019
Mfr. No. 4 85% Magnesia	1.275	1.224	1.181	1.143	1.113	1.082	1.056
Nonpareil	1.415	1.361	1.313	1.279	1.251	1.220	1.196
Asbesto-Sponge Felted	1.045	1.038	1.033	1.026	1.021	1.014	1.010
Hi-Temp	1.347	1.285	1.230	1.185	1.150	1.115	1.085
2 Point	1.306	1.260	1.240	1.212	1.195	1.166	1.155
Imperial	1.515	1.474	1.441	1.409	1.383	1.360	1.345
Carocel	1.349	1.340	1.333	1.323	...	...	...
Pyrex	1.200	1.196	1.186	1.175	1.172	1.166	1.160
Air Cell	1.520	1.550	1.580	1.605	...	...	...
Asbestocel	1.535	1.565	1.610	1.649	...	...	...
Fire-Felt 1 in. thick	2.206	2.118	2.040	1.979	1.927	1.877	1.840
Fire-Felt 1 1/2 in. thick	2.090	2.011	1.927	1.865	1.811	1.761	1.722

TABLE 3 ASSUMED CANVAS TEMPERATURE DIFFERENCE FOR BEST-GRADE COVERINGS

Pipe size in inches	Covering 1 in. thick. Temp. diff., pipe to room 200	300	400	500	600	Covering 1 1/2 in. thick Temp. diff., pipe to room 200	300	400	500	600	Covering 2 in. thick Temp. diff., pipe to room 200	300	400	500	600	Covering 3 in. thick Temp. diff., pipe to room 200	300	400	500	600	Covering 4 in. thick Temp. diff., pipe to room 200	300	400	500	600
1/2	22	34	46	58	71	15	23	32	41	50	10	18	25	31	38	8	13	18	22	27	5	8	12	15	14
3/4	23	36	48	60	74	16	25	35	44	53	11	19	26	33	40	8	14	19	23	28	5	8	13	16	26
1	24	37	50	64	78	17	27	36	45	56	12	20	27	34	43	8	14	20	24	30	6	9	14	18	28
1 1/4	26	40	54	68	82	18	28	38	48	59	13	21	28	35	46	9	15	21	26	31	6	10	15	19	20
1 1/2	27	42	56	71	85	19	29	40	51	61	14	22	29	37	47	9	15	21	·28	33	6	11	16	20	21
2	29	44	58	73	88	20	32	42	54	65	15	23	31	39	49	9	16	22	30	35	7	12	17	21	22
2 1/2	30	45	60	76	91	21	33	45	57	68	16	24	33	41	52	10	17	23	31	37	7	13	18	23	23
3	31	46	62	78	94	22	34	47	59	71	17	25	35	43	55	11	17	24	32	39	8	14	19	24	34
3 1/2	32	48	64	80	97	23	35	48	60	73	18	26	37	45	58	11	18	25	33	40	8	14	20	25	35
4	34	50	66	82	99	24	36	49	62	75	19	28	39	47	60	11	18	26	33	41	9	15	21	26	36
4 1/2	34	51	67	83	100	25	37	50	64	77	19	29	40	50	62	12	19	27	34	43	9	15	21	27	38
5	35	52	69	86	103	26	38	51	65	78	20	30	41	52	63	12	19	28	35	44	10	16	22	28	39
6	36	53	70	87	105	26	39	52	67	80	20	30	42	54	64	13	20	29	37	45	10	16	23	29	30
7	37	55	72	88	107	27	40	54	68	82	21	31	43	55	66	13	21	30	39	47	11	17	23	30	32
8	38	56	74	90	109	28	41	56	69	84	21	31	44	56	67	14	22	31	40	49	11	17	24	31	33
9	39	57	76	92	111	29	42	57	70	86	22	32	45	57	68	14	23	32	41	50	11	18	25	32	39
10	40	58	77	94	113	30	43	58	71	88	22	33	46	59	70	15	23	33	42	51	12	19	26	34	40
12	40	59	78	96	114	30	44	59	73	90	23	34	48	61	72	15	24	34	44	53	12	20	27	35	42
14	41	60	79	98	116	31	45	60	75	92	23	35	49	62	74	16	25	35	45	55	13	20	28	36	43
16	42	61	80	100	118	31	46	62	77	94	24	36	50	63	76	16	26	36	46	56	13	21	28	37	44
18	43	62	81	101	119	31	47	63	79	95	24	37	51	64	78	17	27	37	47	57	13	21	29	37	45

TABLE 4 ASSUMED CANVAS TEMPERATURE DIFFERENCE FOR MEDIUM-GRADE COVERINGS

Pipe size in inches	Covering in. thick Temp. diff., pipe to room 200	300	400	500	600	Covering 1 1/2 in. thick Temp. diff., pipe to room 200	300	400	500	600	Covering 2 in. thick Temp. diff., pipe to room 200	300	400	500	600	Covering 3 in. thick Temp. diff., pipe to room 200	300	400	500	600	Covering 4 in. thick Temp. diff., pipe to room 200	300	400	500	600
1/2	32	49	66	83	100	22	35	48	61	74	16	26	37	47	58	10	18	26	33	41	7	13	19	25	30
3/4	33	51	68	86	104	23	37	51	64	78	17	28	39	50	62	11	19	28	35	43	8	14	21	27	32
1	34	52	71	89	108	25	39	53	68	82	18	30	42	53	65	12	20	29	37	45	9	15	22	28	34
1 1/4	36	55	74	92	112	26	41	56	71	85	19	31	44	55	67	13	21	30	39	47	9	16	23	29	36
1 1/2	39	58	77	96	116	27	43	58	73	89	20	33	46	58	70	14	22	31	41	49	10	17	24	30	38
2	42	61	81	100	120	29	45	61	77	93	22	35	48	61	74	15	24	33	43	52	11	18	26	32	40
2 1/2	44	63	83	103	123	30	48	64	81	97	23	37	50	64	77	16	25	35	45	55	11	19	28	35	43
3	46	66	86	106	127	32	50	67	84	101	25	39	53	67	81	16	27	37	48	59	12	20	29	37	46
3 1/2	47	67	88	108	129	33	51	69	86	104	26	40	55	69	84	17	28	39	49	61	12	21	30	39	48
4	48	69	90	110	131	34	52	70	88	107	27	41	57	71	86	18	29	40	51	63	13	22	31	41	50
4 1/2	48	70	91	112	133	35	53	71	89	109	27	42	58	72	87	19	30	41	52	65	13	23	32	42	52
5	50	71	92	113	135	36	54	73	91	111	28	44	60	74	89	20	31	42	54	66	14	24	33	43	53
6	51	73	94	115	137	37	55	74	93	112	28	46	62	76	91	20	32	43	55	67	15	24	34	44	54
7	52	74	96	117	139	38	56	75	95	114	29	47	63	78	93	21	33	45	57	69	15	25	35	45	55
8	53	75	98	119	141	39	58	77	96	115	30	48	63	80	95	21	34	47	59	72	16	26	36	46	56
9	55	77	100	122	144	40	59	78	97	116	30	48	64	81	98	22	35	48	61	74	16	26	37	47	57
10	56	79	102	124	146	41	60	79	98	117	31	49	65	82	100	22	36	49	62	76	17	27	38	48	58
12	58	81	104	126	148	42	62	81	100	119	33	51	67	84	102	23	37	51	64	78	17	28	39	50	59
14	59	82	105	128	150	43	63	83	102	122	34	52	69	86	104	24	38	52	66	80	18	29	41	52	61
16	60	83	106	129	152	44	64	85	104	125	35	53	71	88	106	25	39	53	68	82	18	30	42	53	64
18	61	84	107	130	153	45	65	86	106	127	36	54	72	90	108	25	40	54	69	83	19	31	43	54	66

engineers will allow 85% Magnesia to be used at this temperature of 606 deg. fahr., but the damage to asbestos products subjected to such high temperatures as 608 deg. is so serious as to make their use under these conditions anything but advisable.[1]

The various steps involved in the solution of problems of this type will be illustrated by an example. Let it be required to determine the heat flow in B.t.u. per hour per square foot of pipe through a compound insulation on a 6-in. pipe consisting of a first layer of Hi-Temp $1^1/_2$ in. thick and a second layer of Mfr. No. 1 85% Magnesia 2 in. thick. The temperature of the pipe is 750 deg. fahr. and the room temperature is 70 deg. fahr.

From conductivity curves Nos. 50 and 57, Fig. 9, it is seen that the conductivity of Hi-Temp. is slightly higher than that of magnesia, so it may be assumed that a canvas temperature difference slightly higher than that indicated in Table 3 for a covering 3 in. thick at 600 deg. temperature difference exists since in this case the covering is $3^1/_2$ in. thick and the temperature difference is 680 deg. Assume a temperature difference of 46 deg. or a canvas temperature of 116 deg. The total drop in temperature through the two coverings = 750 — 116 = 634 deg. The next step is to assume the temperature drop through each insulation, in order to determine the conductivity value to use. No rule can be given for the first assumption, but it will be found that the second one can be calculated very closely. We know from curves Nos. 50 and 57 that the drop through Hi-Temp should be less than the drop through Magnesia, so we first assume a drop of 330 deg. fahr. through Magnesia and a drop of 304 deg. fahr. through Hi-Temp.

Let T_0 = temperature between the outer surface of Hi-Temp and the inner surface of Magnesia, then $T_1 = 750$, $T_0 = 446$, and $T_2 = 116$, and the corresponding mean temperature of Hi-Temp = $(750 + 446)/2 = 598$ deg., while the mean temperature of Magnesia $= (446 + 116)/2 = 281$. From curve No. 57 K_1 for Hi-Temp = 0.658 and from curve No. 50 K_2 for Magnesia = 0.497.

Now

$$r_1 = 3.3125 \quad r_2 = 4.8125$$

$$r_3 \log_e \frac{r_2}{r_1} = 2.55, \quad \text{and} \quad r_3 \log_e \frac{r_3}{r_2} = 2.378$$

Substituting the values obtained above in Equation [5],

$$h = \frac{750 - 116}{\dfrac{6.8125 \log_e \dfrac{4.8125}{3.3125}}{K_1} + \dfrac{6.8125 \log_e \dfrac{6.8125}{4.8125}}{K_2}}$$

$$= \frac{634}{\dfrac{2.55}{0.658} + \dfrac{2.378}{0.497}} = \frac{634}{3.87 + 4.79}$$

$$= 73.2$$

Substituting this value in the surface-loss equation and obtaining by interpolation the value of 343 for $\dfrac{564}{13.6^{0.19}}$ from Table 2,

$$T_d = \frac{272.5 \times 73.2}{73.2 + 343} = 48.1$$

This checks fairly closely with 46 deg. first assumed. It is known that, provided the separate temperature drops through each covering were assumed approximately correct, the correct T_d will be very near to 48 deg.

The temperature drop through Hi-Temp will be approximately = $3.87 \times 73.2 = 283.5$ deg., and the drop through Magnesia approximately $4.79 \times 73.2 = 350.5$. Next assume a canvas temperature of 118 deg. with the corresponding total drop through the insulation of 632 deg. fahr. Since 2 deg. less drop has been assumed through the insulation a corresponding drop of 1 deg. will be assumed through each insulation, or the drop through Hi-Temp = 282.5 deg. and the drop through Magnesia = 349.5 deg. The mean temperature of the Hi-Temp then = 608.7 deg. and $K_1 = 0.661$, the mean temperature of the magnesia = 292.7 deg. and $K_2 = 0.501$, whence

$$h = \frac{632}{\dfrac{2.55}{0.661} + \dfrac{2.378}{0.501}} = 73.4 \text{ B.t.u.}$$

and

$$T_d = \frac{272.5 \times 73.4}{73.4 + 343} = 48.1 \text{ deg. fahr.}$$

This value checks with the value of 48 deg. last assumed and the heat loss = 73.4 B.t.u. The total heat loss per sq. ft. of pipe surface per hr. is therefore

$$73.4 \times \frac{6.8125}{3.3125} = 150.9 \text{ B.t.u.}$$

and the temperature at the inner surface of the magnesia = 467.5 deg. fahr.

[1] *Jour. A. S. H. & V. E.*, July, 1920, p. 543.

Discussion

L. B. McMillan.[1] The method of presenting conductivities of insulating materials as functions of the mean temperatures of the materials is preferable to that in which conductivities are plottted as functions of temperature difference.

The author shows conductivities for several of the materials at mean temperatures up to 650 deg. fahr. If these curves were plotted by the method which he describes, it must have been necessary to make tests at pipe temperatures up to about 1000 deg. fahr. in order to have a mean temperature of 650 deg. fahr. Many of the materials are entirely unsuitable for such temperatures. On the other hand, if the higher ranges were obtained by extrapolation from conductivities determined at lower mean temperatures, the results are misleading, because this would mean continuing the curve through a range of temperatures where admittedly physical changes have taken place.

The description of the apparatus which was used is very meager. Were the test pipes just three feet long overall, or does this refer to the test section exclusive of the portions surrounding the end heaters?

The apparatus as described seems similar in principle to that described by Bagley, in the paper he presented in 1918.[2] Was the feature involving three separate sections of pipe, over the three sections of heater, separated by means of asbestos board used in these tests? The writer is under the impression that a solid pipe has been used by the author, to some extent at least, since the Bagley experiments. If this was done, what assurance is there that there was not excessive end flow of heat?

Apparatus similar in principle has shown that only about 40 per cent of the total input is chargeable to the test section, the remaining 60 per cent being supplied to end heaters; therefore only slight lack of adjustment of these heaters could be expected to cause large errors in the amount charged to the test section. End sections shorter in proportion to the test section would reduce but would by no means eliminate this liability of error.

Were the thermocouples applied only along the top of the pipe or were they distributed around the circumference of the pipe? This is very important, since misleading temperatures, especially on the larger pipe sizes, are likely to be obtained if the thermocouples are not properly distributed.

Were the thermocouple leads brought straight out through the insulation, or were they carried along the pipe under the insulation for a considerable distance before being brought out? Leads which are brought straight out through the insulation are highly subject to error from two causes: namely, (1) conduction along the wires, and (2) the possibility of contact between the wires at a point slightly beyond the surface of the pipe.

The author states that the curves of losses through insulation plotted against temperature difference between pipe and room are all straight lines and suggests that curved lines presented by former

[1] Johns-Manville Co., New York, N. Y. Mem. A.S.M.E.

[2] The Conservation of Heat Losses from Pipes and Boilers, Glen D. Bagley. Trans. A.S.M.E., vol. 40, p. 667.

investigators were perhaps due to inaccuracies in their tests. He also states that the conductivity curves of all of the insulations tested followed a straight-line law. Certain inaccuracies must be present in the author's tests if he finds that both of these curves for a given material are exactly straight lines, because, while it might be true that the curves could be *approximated to with a sufficient degree of accuracy by straight lines*, it is impossible for both curves to be exactly straight lines on account of variations caused by the surface effect included in one of the curves and not in the other.

Furthermore, in many insulations, notably those having relatively large air spaces, the transmission of heat is largely by radiation and convection, neither of which is a linear function with respect to temperature. Therefore it seems certain that the author's straight lines for such materials must indicate experimental error. This conclusion is further verified by consideration of the slopes of certain of the curves, as will be pointed out later.

The author speaks of the convenient relationship shown by Hering and Barrett, namely, that average conductivity is equal to true conductivity at the arithmetical mean of the two surface temperatures. Perhaps he was not aware of the fact that this relationship applies with a satisfactory degree of accuracy to conductivity curves of considerable curvature as well as to straight lines. The proof of this proposition is as follows:

Let k represent the true conductivity which varies with temperature according to the equation

$$k = at^n + b$$

in which a and b are constants.

$$H = \int_{T_1}^{T_2} - kSdt = \int_{T_1}^{T_2} - aSt^n dt + \int_{T_1}^{T_2} - bSdt$$

where S is a shape factor and a is a constant dependent upon the size and shape of the specimen. Let K represent the average value of the conductivity; then

$$H = KS(T_1 - T_2)$$

$$\therefore K(T_1 - T_2) = a\int_{T_1}^{T_2} - t^n dt + b\int_{T_1}^{T_2} - dt$$

$$K(T_1 - T_2) = \frac{a(T_1^{n+1} - T_2^{n+1})}{n+1} + b(T_1 - T_2)$$

$$K = a\frac{T_1^{n+1} - T_2^{n+1}}{(n+1)(T_1 - T_2)} + b$$

$$\therefore K = k \text{ when } t^n = \frac{T_1^{n+1} - T_2^{n+1}}{(n+1)(T_1 - T_2)}$$

or the average conductivity is equal to the true conductivity at the temperature

$$t = \sqrt[n]{\frac{T_1^{n+1} - T_2^{n+1}}{(n+1)(T_1 - T_2)}} \quad \ldots\ldots\ldots\ldots\ldots [6]$$

This relation is general, regardless of the shape of the curve of conductivity with respect to temperature. If this is a straight line, then $n = 1$ and $K = k$ when $t = (T_1 + T_2)/2$, or the average conductivity is equal to the true conductivity at the arithmetical mean of the surface temperature.

But the most interesting feature is that $(T_1 + T_2)/2$ very closely approximates the value of t given in Equation [6] for a considerable range of values of n as illustrated in Table 6, where values are compared for the curve, when $n = 2$.

TABLE 6

T_1 (Abs.)	T_2 (Abs.)	$\frac{T_1 + T_2}{2}$	Values of t from Eq. [6]	Variation from mean	Variation in conductivity[1]
500	600	550	550.8	0.8	0.0004
500	700	600	602.8	2.8	0.0014
500	800	650	655.7	5.7	0.0029
500	900	700	709.5	9.5	0.0047
500	1000	750	763.8	13.8	0.0069
1000	1100	1050	1050.4	0.4	0.0002
1000	1200	1100	1101.5	1.5	0.0008
1000	1300	1150	1153.3	3.3	0.0016
1000	1400	1200	1205.5	5.5	0.0028
1000	1500	1250	1258.3	8.3	0.0041

[1] Based on a rate of change of conductivity of 0.05 per 100 deg. fahr., which is high.

Even in the case of a curve in which conductivity varies as the square of the temperature, the slight errors due to lack of agreement of the above expressions are well within the limits of experimental error. Furthermore, even these errors, small as they are, almost completely disappear in actual use if mean temperatures are determined on the same basis when plotting curves as when using them.

Therefore the convenient relationship to which the author refers applies so accurately to curves of slight curvature that its advantages may be utilized without the necessity of approximating test results by means of straight lines.

Referring to the actual values of conductivity given, the author has indicated the names of the manufacturers of most of the materials; therefore it would be of interest to have this information also for the various tests of 85 per cent Magnesia reported in order to permit comparison of the results with those of other investigators.

The writer has tested many of the same materials as are shown in the author's tests, and the greatest diversity between the results is shown by the tests of Multi-Ply. Fig. 18 shows the writer's

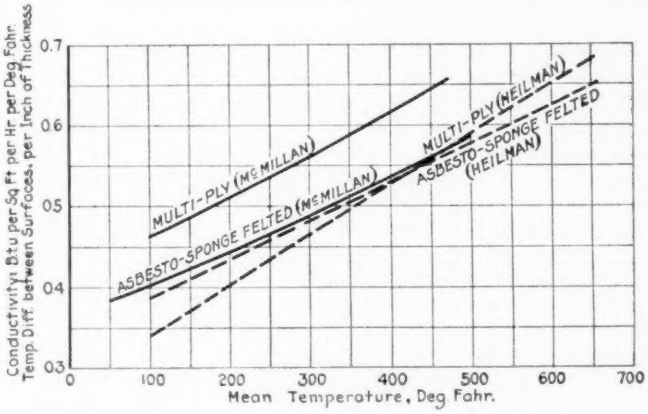


Fig. 18 Tests of Asbesto-Sponge Felted and Multi-Ply Coverings

tests on samples of Asbesto-Sponge Felted and Multi-Ply purchased on the open market. On the same figure are plotted the author's results for comparison. It will be noted that the two tests agree very closely on Asbesto-Sponge Felted, but that the writer's conductivities for Multi-Ply are about 20 per cent higher than those shown by the author. The writer has made six different tests on Multi-Ply and the curve shown in Fig. 18 represents the lowest conductivities shown by any of those six tests.

The constructions of Imperial and Pyrex are very similar; therefore it would be of interest to have an explanation as to why the conductivities of Pyrex are shown to be so much lower than those of Imperial. The writer has tested materials of this nature and has found no such wide difference.

Is the author aware of the fact that if the conductivities of Multi-Ply, Air Cell, and Asbestocel really follow a straight-line law as he states that they do, the slope which he has shown for these materials would cause the curves to intersect the zero axis of conductivity at a temperature considerably above absolute zero? Thus the materials would be shown to have negative conductivities at temperatures between this point of intersection and absolute zero. This is a condition which is obviously impossible and is conclusive evidence of experimental error of large magnitude, and pipe-covering factors shown in the paper in Table 5 and Figs. 13 to 17, inclusive, could not be used where accurate comparisons are desired. All these factors are referred to Multi-Ply as unity, and, as pointed out above, this test cannot be accurate. Furthermore, the factors are contradicted by the author's own curves. The factors in Table 5 indicate that the losses through all the other materials tested at all the temperature differences shown are higher than those through Multi-Ply, yet the curves representing average test results contradict this in several instances.

P. Nicholls.[1] The author lays considerable stress on the straight-line relationships of the unit rate of heat loss to the temperature difference of hot surface to air, and of the average conductivity to

[1] Research Laboratory, American Society of Heating and Ventilating Engineers, Bureau of Mines, Pittsburgh, Pa.

mean temperature of the covering. The latter statement is also the criterion that the relationship of conductivity to temperature will also be a straight line.

No details of any one test are given, and the curves are stated to be averages of several tests and samples. It would therefore seem that instead of emphasizing the rigidity of the relationship it might have been more consistent to state that a straight line represents an average sufficiently correct for commercial purposes.

That the conductivity for a given sample has a straight-line relationship for all materials is questioned, and from a number of tests analyzed it was found to have a convex curvature to the temperature axis. This was done by the method described in a paper by the writer read before the American Society of Heating and Ventilating Engineers in June, 1922.

If it be assumed that the conductivity is a straight line, then if this be combined with the surface-loss equation to obtain the unit loss from pipe to air, it is evident that the combination will not be a straight-line equation.

Such a method of percentages is, however, useful in condensing the information into a small space, and should be good enough for approximate values.

The author states that various samples of a given commercial material may vary in their conductivity, although he only shows the order of the variation for 85 per cent Magnesia. That such variations will occur is to be expected, and it is to be presumed that a manufacturer can more or less control them. Also they may be more pronounced at one period of manufacture than at another, or the average of one period may differ from that of another. In close competition large purchasers are interested in having a guarantee on the material purchased, and on being able to check the material received with the specification value. Conductivity tests are too expensive to use on a large scale, and it is therefore desirable that the relationship of the conductivity to other physical properties, which can more easily be inspected for, should be known. This should be possible, although naturally it would vary with each material.

It would seem advisable, therefore, that investigators should make a special effort to connect their test results with the variations in physical properties and to attempt to obtain some relationship. Except as far as this is done, purchasers will be at a loss as to which of several values they shall accept.

All heat transfer from pipe to air is naturally explained by direct conduction through the material. It is an interesting question, however, as to whether there may not be some air movement through porous materials, due either to temperature diffusion, pressure difference, or to natural infusion of the convection currents. It is perfectly legitimate to treat this—should it occur—as equivalent conductivity, but if it were of an appreciable amount it would upset the natural laws usually assumed.

T. S. TAYLOR.[1] It is a rather remarkable fact that the relation between B.t.u. per sq. ft. per deg. fahr. per hour and the temperature difference in deg. fahr. pipe to room, is a straight-line one. The experiments by the writer on the measurement of absolute thermal conductivity have indicated that the increase of thermal conductivity with increase in temperature is not uniform. In some cases there has been a falling off of the rate of increase, and in others it has increased more rapidly than the straight-line relation. We would not naturally anticipate a perfectly straight-line relationship between absolute thermal conductivity and temperature since the factors causing this thermal conductivity to increase with temperature do not vary directly with the temperature. The increase may be due to several causes, although at the present time we are not in a position to put our fingers on absolute proof of the magnitude of the influence of the various causes. In the case of absolute thermal conductivities the factors involved are relatively few compared with those involved when overall conductivities are given such as are plotted for the most part in the author's paper. The loss of heat by radiation from the surface of a body varies as the fourth power of the absolute temperature. This quantity is a relatively good percentage of the total external loss in free convections. Then the loss by free convection alone certainly varies as the power differs from unity. Consequently it seems very striking that an overall relationship which embodies components varying with different powers of the absolute temperatures should vary directly as the temperature. It is the opinion of the writer that when we are able to calculate definitely the various components of the heat losses, we will find that the linear relationship does not exist absolutely over any great range in temperature. For practical purposes, however, there is little question but that the linear relation can be used with perfect safety.

[1] M. & P. Engine Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa. Mem. A.S.M.E.

In regard to the general use of the equation,

$$T_d = \frac{272.5h}{h + \dfrac{564}{D^{0.19}}}$$

this is a purely empirical relationship which certainly can hold only for a limited range of pipe sizes. It is quite likely that the relation is sufficiently accurate to give satisfactory results for pipes of ordinary commercial size, but it would be necessary to use considerable precaution in extending this indefinitely both to small pipes and to very large pipes. It would have been of interest had the author plotted the relation between thermal conductivity and average temperature of the pipe covering. While it is a little troublesome to calculate the actual average temperature of the covering, it nevertheless can be readily done. The writer has on different occasions plotted the relation between thermal conductivity and average pipe temperature and compared the same with the thermal conductivity plotted against the average of the external and internal temperatures. These relations were not exactly of the same nature.

H. N. DAWES.[1] The paper is open to the criticism that undue prominence is given to the products of one manufacturer. Much is said about a covering called Hi-Temp for use as an inner layer under standard 85 per cent Magnesia Sectional on superheated-steam lines. Doubtless other manufacturers than the makers of Hi-Temp are producing an inner-layer covering of higher refractory and lower heat-insulating value than the regular 85 per cent Magnesia in order to meet the requirements of any engineer who may desire such a composite covering.

Eighty-five per cent Magnesia coverings, however, have stood up successfully under temperatures of 750 deg. fahr. The writer has seen some of this covering which had been in use for many months at one of the large electric power stations, subjected to a temperature well above 750 deg. fahr., in which scarcely any calcining of the magnesia carbonate was discernible.

The extremely narrow range of variation in heat losses under similar conditions for the best of high-pressure coverings on the market, as indicated in the author's tables and also in L. B. McMillan's paper[2] presented to the Society in December, 1915, indicates to the practical engineer that other considerations than heat conductivity under laboratory conditions are possibly of as great or greater importance in placing insulation contracts. The life of the covering and its insulation value after several years should be considered. The deteriorating effect of repeated wettings and dryings, the nature of the plastic material used on fittings and irregular surfaces, and—most important of all—care in application are worthy of much more careful consideration than they often receive.

EUGENE DOWLING.[3] While the results of scientific investigations of this character made by manufacturers are usually correct and reliable, yet more weight is generally assigned to disinterested experiments. It is appropriate, therefore, to ask whether there was any connection between the author or the Mellon Institute of Industrial Research and the manufacturers, whether manufacturers were all represented on an equal basis, and whether, during the progress of the tests they were advised that such tests were being carried on.

R. D. DEWOLF.[4] It would be interesting to know whether the author has done any work to determine whether there is any difference between the rate of heat transmission in steam lines carrying saturated steam and in steam lines carrying superheated steam.

In 1922 the Rochester Gas & Electric Corporation had an opportunity to test an 8-in. suspended line about 1800 ft. long, covered

[1] Nightingale & Childs, Boston, Mass. Mem. A.S.M.E.

[2] The Heat-Insulating Properties of Commercial Steam-Pipe Coverings, Trans. A.S.M.E., vol. 37, p. 921.

[3] Johns-Manville Co., Cleveland, Ohio. Mem. A.S.M.E.

[4] Chief Operating Engineer, Rochester Gas & Elec. Corp., Rochester, N. Y. Mem. A.S.M.E.

with 2 in. of magnesia, two layers of 1-in. hair felt, and a layer of building paper outside.

One test was run when this line was carrying a heavy load, and the temperature loss was obtained from the difference in the temperatures of the steam entering the pipe at one end and leaving at the other. The steam was superheated, and there was no condensation taking place in the line.

The other test was made by simply blocking the line off at the end and keeping it full of steam. This approximated a condition of saturated steam. It was found that the B.t.u. loss per sq. ft. per degree difference of temperature with superheated steam based upon the difference between the temperature of the superheated steam and the temperature of the air was about one-half of what it was when using saturated steam, which in turn was based upon the difference in temperature of the saturated steam and the air. That indicates that in the case of superheated-steam lines if a constant taken from work with saturated steam is used, a serious error may result. The difference is due to the rate at which the column of steam in the pipe transmits heat to the surface of the pipe. If it contains saturated steam, the inner surface of that pipe is wet, and it probably absorbs heat much more rapidly than it does in the case of superheated steam where the inner surface of the pipe is dry.

THE AUTHOR. Since several of the gentlemen discussing this paper have raised the same question in regard to the straight-line relationship of the thermal conductivity and since this is apparently the most important point brought out in the discussion, the author will reply to this question first.

It will be noted in the paper that the heat-loss curves are all represented as straight lines. There is no doubt in the author's mind that these curves are correct and the reason for their being straight lines is attributed to the fact that they were obtained from tests conducted with the utmost care and accuracy. The tests on the Air-Cell and Asbestocel coverings were the only ones whose curves showed any signs of deviating from a straight line, and these tests gave points so near to a straight line that it was almost impossible to draw anything but a straight line through them.

The statement is made on the third page of the paper that in all the tests on commercial insulating coverings conducted during this investigation there was no covering tested whose conductivity did not obey a straight-line law. While the author is aware of the fact that if the heat-loss curve, which is a straight-line curve, is combined with the surface-loss equation, which is not exactly a straight-line curve, to obtain the conductivity curve, an exactly straight-line conductivity curve will not result. However, the resulting curve will be so near to a straight line that no engineer would hesitate in calling it a straight line, and from the calculations which follow the author is of the opinion that for the temperature range for which the coverings tested are suitable, even the most exacting physicist would not hesitate to state that the conductivity curves follow a straight-line law.

If we take, for example, the heat-loss curve for the Multi-Ply covering shown in Fig. 2, and calculate the equivalent thermal conductivity for this covering from the curve given and the surface-loss equation for the two extreme points of 100 and 600 deg. temperature difference between pipe surface and air and the central part of the curve or 350 deg. temperature difference, we will have the following:

Assuming the room temperature to be 70 deg. fahr., at 100 deg. temperature difference the total heat loss per square foot of pipe surface is $0.357 \times 100 = 35.7$ B.t.u. Since the average thickness of the covering was 1.05 in., the total heat loss per square foot of canvas surface is $35.7 \times (1.75/2.80) = 22.3$ B.t.u. The temperature difference between the canvas surface and the air is equal to $(272.5 \times 22.3)/(22.3 + 407)$ or 14.16 deg. The temperature drop through the covering is then $100 - 14.16$ or 85.84 deg. The

$$\text{equivalent conductivity} = \frac{35.7 \times 1.75 \log_e (2.80/1.75)}{85.84} = 0.341 \text{ B.t.u.}$$

The mean temperature $= (170 + 84.16)/2 = 127.1$ deg. fahr.

At 600 deg. temperature difference the heat loss per square foot of canvas $= 0.559 \times 600 \times (1.75/2.80) = 209.7$ B.t.u. The temperature difference between the canvas and air $= (272.5 \times 209.7)/(209.7 + 407) = 92.7$ deg. The equivalent conductivity $= (335.4 \times 0.820)/507.3 = 0.542$ B.t.u. The mean temperature is $(670 + 162.7)/2 = 416.35$ deg.

At 350 deg. temperature difference the heat loss per square foot of canvas surface is $0.458 \times 350 \times (1.75/2.80) = 100.1$ B.t.u.

The temperature difference between canvas and air is $(272.5 \times 100.1)/(100.1 + 407) = 53.8$ deg.

The equivalent conductivity is then equal to $(160.2 \times 0.820)/296.2 = 0.4435$ B.t.u. and the mean temperature $= (420 + 123.8)/2 = 271.9$ deg.

A straight line can be expressed by the equation $x = ay + b$. In this case y = equivalent conductivity, x = mean temperature, and a and b are constants. Substituting the values of mean temperature and equivalent conductivity for the two extreme points in the above equation and solving the resulting simultaneous equations we obtain $a = 1439$ and $b = -363.9$.

The equation of the curve which passes through the two extreme points calculated is then $x = 1439y - 363.9$.

Now if we substitute in this equation the value of 271.9 deg. mean temperature obtained for the calculation of 350 deg. temperature difference, we have $271.9 = 1439y - 363.9$, or $y = 0.4415$ B.t.u. The value obtained by calculating the equivalent conductivity from the heat-loss curve and the surface-loss equation was 0.4435 B.t.u. The deviation from a straight line is thus found to be only four-tenths of one per cent. Furthermore, as the curves obtained were the average conductivity curves of 1 in., 2 in., and 3 in. thickness, the greatest deviation will be for the 1 in. thickness, so that when the average of the three curves is taken the actual deviation from a straight-line law will probably be less than three-tenths of one per cent. It would be impracticable even for the most exacting work to assume anything other than a straight-line law for the temperature range shown. However, for temperatures as low as absolute zero or for temperatures considerably above the temperature range for which the coverings are intended it would be unreasonable to expect the conductivity curve to follow the same law as for ordinary temperatures.

The author is of the opinion that, for the majority of the insulations used at present, the internal radiation and convection are relatively unimportant in comparison with the heat transmission by conduction or contact.

Tests made by the author which are not included in this report tend to confirm this statement. It is reasonable to believe that the transmission by conduction alone is a straight-line function of the temperature. Then if the radiation and convection are relatively unimportant, it is reasonable to expect the combination of the three to deviate only very slightly from a straight-line function.

In reply to Mr. McMillan's criticism, the pipe temperature in the heat-loss tests was not raised much above the maximum temperature for which the coverings were recommended by the manufacturers. For instance, the Multi-Ply and Asbesto-Sponge Felted coverings were raised to a pipe temperature of about 600 deg. fahr. The conductivity curves were calculated from the heat-loss curves and extended to a mean temperature of 650 deg. fahr. This procedure will cause little error since neither Multi-Ply nor Asbesto-Sponge Felted are suitable for temperatures as high as 650 deg. and will consequently seldom be used at that temperature. If they should be used at a mean temperature of 650 deg. in some temporary installation, the error in using the extended curves will be very slight.

The description of the testing apparatus as given in the paper is very brief. The main reason for this was to minimize as much as possible the length of the paper. With regard to the accuracy of the apparatus, the author wishes to state that the present apparatus is the gradual development of seven years' work on heat insulations. In the present apparatus 83 per cent of the total power used is supplied to the test section, and 17 per cent to the end sections—not 60 per cent as suggested by Mr. McMillan.

During the development of the testing apparatus at the Institute quite a number of different designs were built and tested. The present apparatus has proved to be much superior to any of the other types, including the type used by Mr. McMillan.[1] The author has checked and rechecked this apparatus, placed couples in different positions, and even gone so far as to build a special apparatus with the couples at the top of the pipe, then 15 deg. from the top, and 30 deg. from the top, etc., the whole way around the pipe, and

[1] Trans. A.S.M.E., vol. 37, p. 921.

has found for the pipe size used that it is absolutely useless to go to such refinements.

On the whole, it is believed that the method of procedure in conducting the tests and the testing apparatus used can be little improved upon.

In regard to Mr. McMillan's tests of Asbesto-Sponge Felted and Multi-Ply coverings shown in Fig. 18, it is very probable that the Multi-Ply coverings tested were old samples and were not typical of the covering as it is made at present. Constant improvements have been made and these coverings are now much superior to those made a year ago, as conductivity tests will show.

Mr. McMillan is very much in error when he states that the constructions of Pyrex and Imperial coverings are similar. Two sections of Imperial were tested. One section contained 15 plies of paper and the other contained 22 plies; the average number of plies to the inch was 20. Pyrex covering has an average of approximately 30 plies to the inch. Pyrex is identical in construction with Multi-Ply, with the exception of the manner in which the layers of paper are cemented together and the amount of bonding material used. The mechanically constructed air pockets in the Imperial covering are much larger than those in the Pyrex. The fact that Mr. McMillan could find little difference in the conductivity values of these two types of coverings is conclusive evidence of inaccuracies either in his testing apparatus or his method of testing.

The factors shown in Table 5 can be used for calculations which do not require absolute accuracy, as stated in the paper.

This table was included in the expectation that it would be of practical value to the engineers who would have occasion to use it. The factors are referred to Multi-Ply as unity, since the average of all the tests on the Multi-Ply coverings indicated that for pipe temperatures up to 700 deg. fahr. this type of covering was superior to the other types. The Multi-Ply coverings were tested in exactly the same manner and with the same degree of accuracy as all the other types of covering, so that the comparisons are accurate and reliable.

The reason that the factors which are shown in Table 5 are all greater than unity is due to the fact that a temperature difference of 700 deg. corresponds approximately to a mean temperature of 450 deg.

In regard to Mr. Dowling's remarks, the author wishes to say that Mellon Institute is an independent research institution and its research work and released reports are strictly unbiased.

The Heat Insulation Fellowship is only a very small part of the whole organization, one of 55 industrial fellowships in operation. It is required that results given out by any fellowship be absolutely fair and confirmable.

Answering Mr. DeWolf, the author has not investigated the difference in the rate of heat transmission for a pipe carrying saturated steam and for one carrying superheated steam. This is a very important question and the author is under the impression that the National Research Council expects to conduct some investigational work on this problem.

The New Conservation

By PAUL E. HOLDEN,[1] WASHINGTON, D. C.

PERHAPS no industrial movement within the past decade has received more widespread attention and application than that of simplification and standardization. There is no implication that the movement had its inception as recently as 10 years—the idea is neither new nor novel.

In fact, Alfred Marshall in his Industry and Trade tells us that, in 1672 the Dutch shipbuilding industry was operating along simplified lines. One community were specialists in the building of keels, another of ribs, another of beams, and so on. These shipbuilders adhered mainly to one pattern for ships of 100 tons and another pattern for ships of 500 tons. Carriage being easy, the different parts of a ship could be ordered from these various specialists and readily assembled at a central point. Thus we find specialization and repetitive processing in practice at least 250 years ago.

The next step closely followed the development of industrial machinery. In the early days of our national existence when currency was scarce, commodity was exchanged for commodity. Factories did not exist, the consumer giving his individual order to the shoemaker, tailor, or other artisan. In due time the consumer demand exceeded the hand-made production, and thus was conceived the manufacturing establishment as we think of it today. The extent to which American inventive genius has made possible the science of mass production, for which this country is known the world over, needs no emphasis. During this period of evolution manufacturers generally have applied simplification and standardization to their processing methods.

However, the full potentialities of the movement were first prominently brought before American industry during the war. The War Industries Board early discovered that to conserve time, materials, and money it was necessary to vastly increase the production and output of each establishment. Over-diversification was found to obtain in virtually all commodity lines and it was imperative that varieties, sizes, types, and so on be reduced to a minimum. No one other than the manufacturers themselves was better able to determine what should be eliminated and what retained, and the United States Chamber of Commerce coöperated with the War Industries Board in organizing the various War Service Committees. These committees set up the reduced schedules under which their respective industries operated. As to the effectiveness of the work, their record stands for itself.

It should be observed that this was during the stress and compulsion of war and, unfortunately, upon the withdrawal of restrictions many reverted to the old order of multiplicity of varieties. Thus it was that the Department of Manufacture of the National Chamber took up as one of its major activities the promulgation of simplification and standardization as a constructive peace-time effort. Thus from a measure of grim necessity it has been adopted by industry as a sound business and commercial policy.

The department in its four years of effort has maintained active contact with some 378 separate and distinct lines of industry. The progress made has been remarkable. Particularly so when it is realized that no persuasion or pressure other than good business judgment has been brought to bear. There are no police powers exercised by any one in determining the simplified schedules nor

Table 1

Item	Reduction in Variety	Percentage Elimination
Paving brick	66 to 5	92
Beds, springs and mattresses	78 to 4	95
Metal lath	125 to 24	81
Woven-wire fencing	552 to 69	87
Fence packages	2072 to 138	93
Asphalt	88 to 9	90
Hollow building tile	36 to 19	47
Face brick	39 to 1	97
Milk bottles	49 to 9	82
Milk-bottle caps	29 to 1	96
Hotel chinaware	700 to 160	77
Files and rasps	1351 to 496	63
Range boilers	130 to 13	90
Bed blankets	78 to 12	85
Forged tools	665 to 351	47
Blackboard slate	90 to 3	97
Laboratory apparatus	2800 to 1400	50
Steel barrels	67 to 25	63
Brass traps	1114 to 72	93
Hospital beds	33 to 1	97
Hot-water tanks	120 to 14	88
Pneumatic tanks	190 to 12	88
Baskets	78 to 11	86
Chilled car wheels	175 to 4	98

[1] Department of Manufacture, Chamber of Commerce of the United States.

in maintaining them—such a plan operates effectively when and only when it is economically sound.

As indicative of what has been accomplished, a few typical simplification results are cited in Table 1.

These instances are those in which an entire industry and trade have coöperated to determine upon the varieties necessary to meet all the real needs and legitimate demands. The action taken was not arbitrary upon the part of any one factor. The producers, distributers, and all other interested elements have had a part in the procedure. The result has been a series of truly representative schedules covering these lines.

Of significance is the wide range of commodities which have been treated, suggesting perhaps that the character of the article does not preclude a reasonable simplification and standardization. As of possible interest, a few of the industries in which simplification projects are now under way are listed:

Builders' Hardware	Refrigerator Hardware
Cold-Water Storage Tanks	Gasoline Storage Tanks
Gas Water Heaters	Dental Tools and Supplies
Rubber Heels	Glove Boxes
Copper and Brass Products	Paint and Varnish Brushes
Milk and Ice-Cream Cans	Wooden Tool Handles
Garden Hose	U. S. Flags
Drills and Reamers	Taps and Dies
Steel Lockers	Copper Boilers
Grocery Bags	Terne Plate
Sheet Steel	Shovels
Clay Products	Pocket Knives
Loaded Shells	Brake Linings
Office Equipment	Piston Rings
Tents and Awnings	Glass Containers
Concrete Products	Cotton Duck
Cardboard	Knitted Outerwear
Saddlery and Harness	Oil Burners
Refrigerating Machinery	Woodworking Machinery
Optical Goods	Woodenware
School Supplies	Paper
Valves and Fittings	Stoves
Steel Sash	Hack Saws
Surgical Dressings	Tacks
Cotton Thread	Collapsible Tubes
Cooking Utensils	

If any one premise may be said to form the basis upon which simplification and standardization is established, it would be—the elimination of waste. The Waste In Industry report submitted in 1921 by a committee of engineers under the chairmanship of Secretary Hoover, pointed out that the avoidable waste in the six major industries studied extended from 29 to 64 per cent—an average of approximately 50 per cent. Even if these engineers were only half right in their assay, one-quarter of the effort, time, and money expended in our factories is utterly lost and nothing is realized from it. Admittedly many sources contribute to this waste and no one factor is responsible for all. Yet it is well recognized that over-diversification and lack of reasonable standards is one of the most outstanding wastes chargeable to management. Fabricated production in the United States will average approximately $50,000,000,000 in value annually. Thus, any salvaging of the avoidable waste in industry through a reasonable reduction in varieties, sizes, and types would be an effort very worth-while. Indeed many industrialists are heeding the watchword that "Tomorrow's Profits May be Largely Realized from Today's Wastes."

There has been some impugnment of the motives back of the simplification movement, prompted, no doubt, by the impression that simplified practice ultimately presages the reduction of all commodity lines to a common pattern or variety. Nothing is further from the actual facts, as individuality and initiative are certainly the last attributes of man which should be disturbed or curtailed.

Moreover, a certain misconception exists concerning the relation of simplification and standardization. To many the two are synonymous, whereas in the way we are using the term there is a very definite distinction. Simplification is a very real means of eliminating some of the avoidable waste in industry and trade. It is based on commercial expediency rather than on scientific fact; technical research and engineering experimentation are not necessary. This statement is not meant to imply that simplification is hit-and-miss or arrived at through "grab-bag" procedure. Quite the contrary is true. Simplification is developed from the best practice and judgment of an industry or individual establishment. Facts are vitally necessary, but production and sales records coupled with a true picture of the consumers' needs are usually sufficient for constructive simplification action. Moreover local, climatic, and other conditions are given consideration.

Simplification when established is not iron-bound but is sufficiently elastic to accomodate varying industrial and marketing situations. Simplification like standardization facilitates development and advancement and has no tendency to stifle individuality. Simplification does not preclude standardization in any line or industry, but standardization often involves simplification at some point in the process of establishing standards.

Summing up, simplification, while comprehending a very definite and real purpose, may rightfully be regarded as complementary to standardization and scientific research.

It is necessary and natural that any movement of the proportions, ramifications, and extent which characterize that of simplification and standardization should head up and be coördinated through some organized plan. This centralizing of effort and action is being accomplished through three coöperating agencies, the Division of Simplified Practice of the Department of Commerce, The American Engineering Standards Committee with its 316 coöperating bodies, and the Department of Manufacture of the United States Chamber of Commerce. Projects involving technical considerations are within the purview of the American Engineering Standards Committee, while those embracing more the commercial aspects are being handled by the Department of Commerce and the National Chamber.

The effectiveness and permanency of industrial simplification and standardization can be secured only through the wholehearted support and endorsement of those in position to impress their influence upon company policies. In this respect the engineers have much to contribute to the ultimate success of the work and all proponents of the movement bespeak their fullest coöperation.

Science at a Discount

THE following editorial which appeared under the above heading in the *Saturday Evening Post* is an indication that the fundamental character of the engineering profession is being realized to a much greater degree.

It would be interesting to determine by extended inquiry which of the learned professions is most poorly paid. Five years ago, if clergymen had been left out of the reckoning on account of their perennially low financial estate, we should have said the college professor was fully entitled to his melancholy precedence at the head of the list of the underpaid. Notable additions to college endowments followed by substantial increases of faculty salaries have materially bettered the professor's lot. He is now several removes from the top of the starvation list.

Engineers, technologists and men of science, taken as a single group must now be at the top or very near the top of the list of the conspicuously underpaid. We exempt from this classification those engaged in selling and those who occupy high executive positions. We include in it those whose work is strictly professional.

Such training represents large investment of money, time, brain power and moral stamina. Higher technical courses cost much to give and much to receive. They require, among other things, laboratories equipped with heavy machinery, instruments of precision and costly accessories of a hundred sorts. Instructors must be men of unusual equipment who know how to teach as well as how to practice. Mathematics is the mainstay of many of these courses, for today the small talk of science is conducted in the vernacular of calculus. The training is severe because it consists largely in the inculcation of principles, and principles are always more difficult to grasp than facts or mere information.

Men of this stamp are notoriously underpaid. Bureau scientists in Washington, conspicuous examples of the faithful public servant, work for salaries that a self-respecting plasterer would call cigarette money. Research men in the laboratories of great corporations fare better, but by no means well. Engineering experts in a dozen fields, well equipped specialists, are often so ill rewarded that they find it hard to live in modest comfort.

These conditions are beginning to produce the inevitable result. Educators who are trying to assist young men in their selection of a career are telling the truth about the engineering professions and are comparing them unfavorably with other fields of activity. Engineers themselves are equally frank when advising their young friends.

From colonial times our people have had a genius for mechanics, invention and applied science. It would be a national calamity if we should be so shortsighted as to starve out this priceless talent. If there is any one thing about our social evolution that is certain, it is our growing dependence upon science to solve the problems of peace and war and everyday life. To weaken by neglect or indifference those powers upon which our future existence may depend would be sheer folly.

The Development of the Electric Locomotive

General Comparison of Steam and Electric Locomotives—Forms of Motor Drive—Electric-Locomotive Rating—Otheograph Tests of Locomotive Impact on Rails, Etc.

By A. H. Armstrong,[1] Schenectady, N. Y.

The first lesson learned by the electric-locomotive designer was the fact that its successful construction did not consist in the simple substitution of the electric motor for the steam cylinder and the adoption of the running gear accepted as good practice after many years of steam-engine development. This in no way implies a criticism of steam-engine construction—which is admirably suited to its purpose under the limitations imposed by engine, boiler, and firebox design. Just as these fundamental parts of the steam engine determine both its construction and service performance, so the electric motor, with its great flexibility, permits a radical departure from steam-engine practice in both the design and operating characteristics of the electric locomotive.

While the design of the steam engine conforms to three or four broad types of construction, arrived at after the long and costly experience of a century's development, the electric locomotive of today presents a much wider variety in design. In fact, the electrical engineer is embarrassed in his attempt to arrive at a standard type of electric locomotive for any class of service, because of the variety of designs available, any one of which may be successful in operation. In consequence, a study of the running gear of electric locomotives now in operation discloses many forms of drive ranging from single gear, twin gear, side rod and jackshaft, geared side rod, quill geared, and finally gearless drive with the motor armature mounted directly upon the driving axle. With any one form of the above drives there is also offered a wide variety of wheel and cab arrangement. No one design of electrical or mechanical construction has yet been universally accepted as a standard to the exclusion of others, although this is the desirable goal toward which the efforts of the designing engineer are constantly directed.

With such a diversity in forms of construction shown in electric locomotives now running, it is the purpose of this paper to discuss in a general way some of the fundamental principles of design which have found favor as the result of the past thirty years' development.

Double-End Operation

With apparently no exception, the first radical departure from steam practice was made when electric locomotives were designed for equally good operation in either direction—in other words, by providing a symmetrical arrangement of running gear so that locomotives could be operated double-ended. The absence of boiler and firebox makes this accomplishment possible and the operating convenience of eliminating the turntable and wye can be taken full advantage of without imposing too serious a burden upon the electric-locomotive designer. In order that the locomotive operator may command an uninterrupted view of the track ahead, cabs are built of two general designs, the so-called "steeple" cab with sloping ends and one operating compartment and the box-type cab with two operating compartments, one at each end. As the motor control of large electric locomotives is effected through indirect or master controllers which can be located in one or more places, it is possible to design the operating cab for the most convenient handling of the locomotive, and provide one or more operating handles as conditions may demand.

The adoption of a symmetrical wheel arrangement, which permits running equally well in either direction, introduces no difficulties in the construction of locomotives which will run below a speed of 50 miles per hour. In other words, the tracking qualities of an electric locomotive do not become a matter of serious concern to the designer until entering upon the field of the passenger locomotive, which must have good running qualities up to maximum speeds of 75 miles or possibly more. Few, if any, steam engines will operate successfully in reverse direction, and in providing this feature of electric locomotives the designer has had to solve new problems without much assistance from steam-engine operating experience. That such problems have been successfully met is attested by the daily operation of electric locomotives in high-speed passenger-train service with less apparent destructive effect on track than is normal with steam-engine operation.

Electrical and Mechanical Designs

The mechanical construction of an electric locomotive is so dependent upon the characteristics of its motors and control that the complete electrical and mechanical design must be treated as one problem. For example, geared motors suspended upon driving axle and bolster must conform to the restricted space imposed by track gage, wheel diameter, and permissible wheelbase of driving truck. These limitations do not seriously restrict the free design of motors geared to small-capacity driving axles but force a departure from geared axle drive in the case of certain types of motors, when axle weights much exceed 40,000 lb. As an illustration, direct-current motors drive the 56,000-lb. axle on the C. M. & St. P. freight locomotives, but it would be impossible to replace them with an equally successful single-phase alternating-current motor on account of the greater space required for the proper proportioning of the latter type of motor. It would also be impossible to replace the gearless direct-current motors on the New York Central, C. M. & St. P. passenger, and Paris-Orleans locomotives with alternating-current motors, as bipolar gearless drive is available only to motors of the direct-current type. On the other hand, all forms of construction open to alternating-current motors are equally available to the direct-current motor.

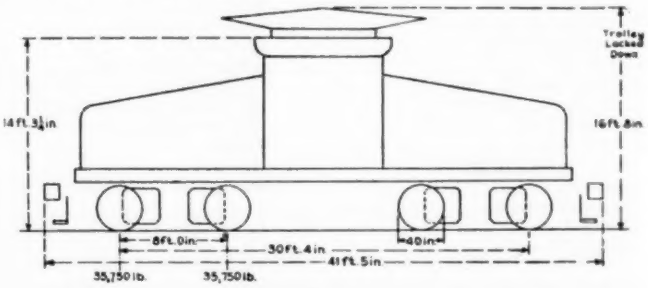


Fig. 1 3000-Volt D.C. 71-Ton Electric Switching Locomotive, C. M. & St. P. Ry.

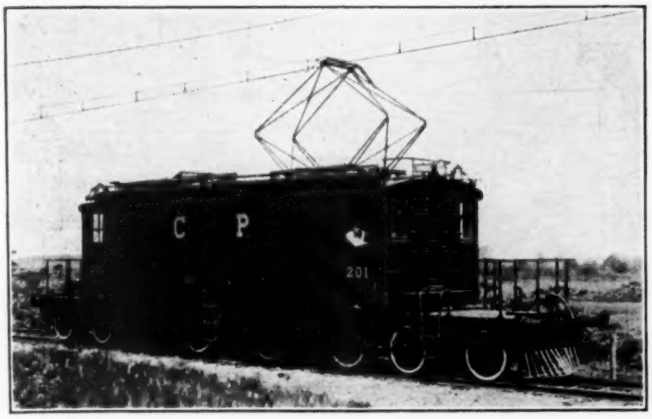
As both direct-current and alternating-current types of motors have been utilized to drive electric locomotives and all forms of drive are not equally available to both, more or less confusion has been introduced into the problem of arriving at a preferred form of mechanical design which might be generally adopted and possibly become a recognized standard. A thorough knowledge of electric-motor characteristics is therefore desirable to arrive at any conclusion in respect to the superiority of any particular mechanical design of locomotive in order to judge whether it possesses inherently the advantages sought for or whether its adoption may have been forced by the limitations of the type of motor used.

General Comparison of Steam and Electric Locomotives

The steam engine is a mobile power house complete with firebox, boiler, engine, and operating crew. In order that the latter may be used to the best economic advantage, every effort has been made to build engines of greater power. In this country of almost unlimited fuel supply, not much serious effort has been made until recently to improve the fuel economy of steam-engine performance except as it might increase the maximum weight and speed of trains hauled. In other words, with cheap and abundant fuel and high-

[1] Chairman, Electrification Committee, General Electric Co.

Contributed by the Railroad Division for presentation at the Spring Meeting, Cleveland, Ohio, May 26 to 29, of The American Society of Mechanical Engineers, 29 West 39th St., New York City. All papers are subject to revision.



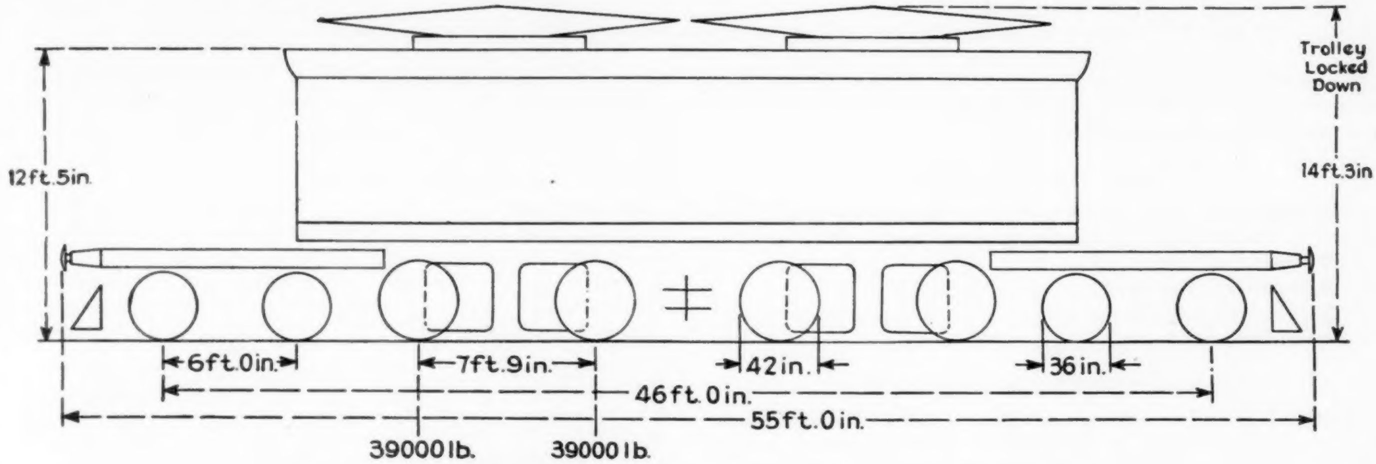


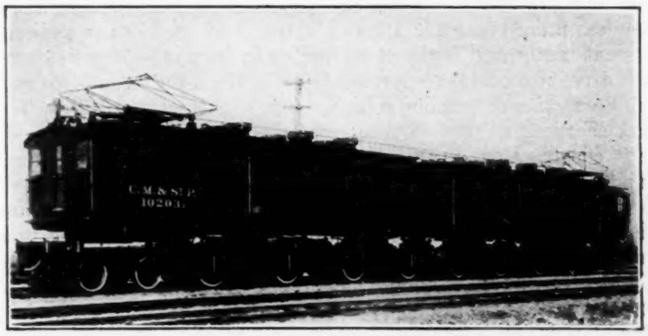
Fig. 2 3000-Volt D.C. 118-Ton Electric Passenger Locomotive, Paulista Ry.

priced labor the matter of fuel economy has been secondary to the insistent demand for engines of greater hauling power and speed.

As each steam engine must necessarily be operated by its own crew and as the improvements made in the modern draft gear permit the operation of trains on ruling grades beyond the hauling capacity of a single engine, it is a logical development that the steam engine should be built with a maximum number of driving axles and maximum weight per axle. Hence, the construction of the Mikado, the 2-10-2, and the Mallet, with axle weights in some instances of approximately 70,000 lb., in an attempt to meet the necessities of constantly increasing traffic. The logical development of the steam engine, therefore, lies apparently in the direction of the maximum driving-axle weight that improved rail and roadbed may permit and the maximum number of axles that can be concentrated in one structure and operated by one crew without exceeding wheelbase restrictions imposed by track curvature.

It is of importance in determining electric-locomotive design to carefully analyze the fundamental reasons for modern steam-engine construction, with which electric locomotives are naturally compared, so that hard-bought steam-engine experience shall be taken advantage of to the fullest extent. Unlike the steam engine, the electric locomotive carries no power plant. Furthermore, the electric motor is wonderfully adaptable in its application to axle drive and small motors are practically as efficient as large ones. These valuable assets make it possible to design an electric locomotive for its sole fundamental purpose of hauling trains with reliability and economy. The same factors shaping the design of running gear of steam engines do not apply equally to electric locomotives, and both in its operation and construction the latter can, with advantage, depart widely from steam-engine precedent. Neither the wheel arrangement, side-rod drive, or excessive axle weights characterizing the modern steam engine are fundamentally necessary to the construction of a successful electric locomotive and they need only be accepted on their merits. With the new freedom thus offered it is natural that the experimental field of promising designs should have been quite fully explored with the resulting wide divergence in mechanical and electrical construction shown in electric locomotives now in operation. The electric locomotive may be built up of any number of driving axles, all under the perfect control of one operator, and there are no electrical, mechanical, or economic limits in respect to its size, hauling capacity, and speed, except those imposed by the roadbed itself.

With the above general comments in mind, perhaps a better



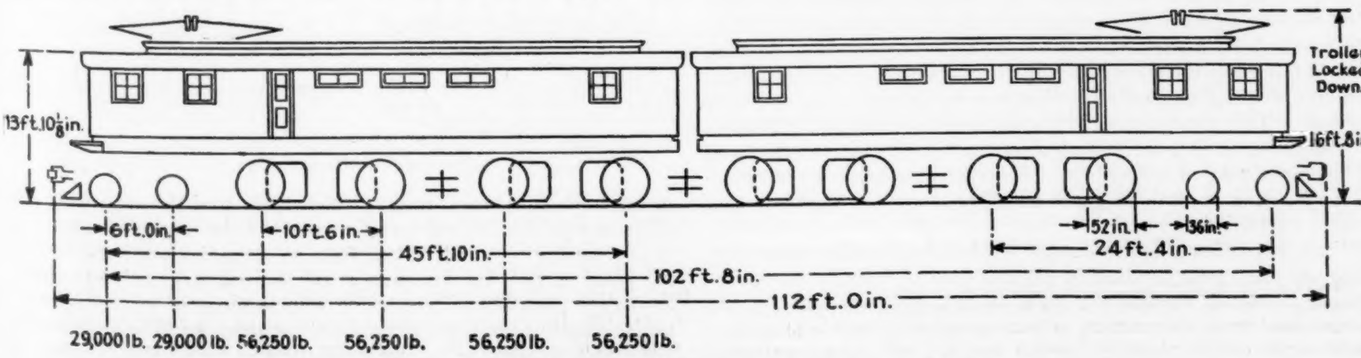


Fig. 3 3000-Volt D.C. 288-Ton Electric Freight Locomotive, C. M. & St. P. Ry.

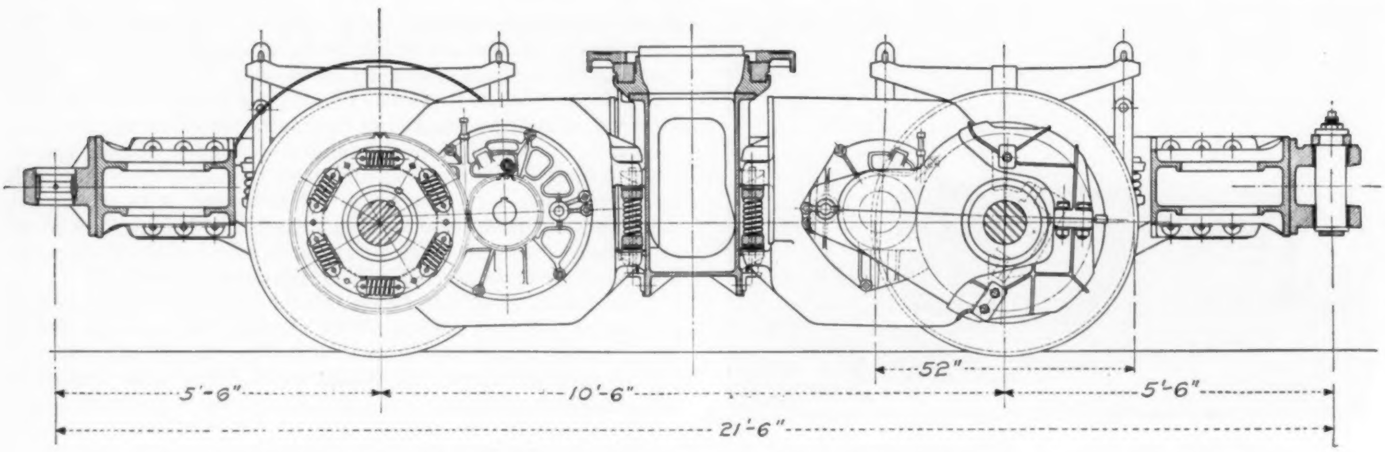


Fig. 4 Longitudinal Section Showing Spring Gear and Spring-Nose Suspension of Locomotive Shown in Fig. 3

understanding of the progress of electric-locomotive development may be obtained by reviewing the construction of a number of recent designs that have been built.

Forms of Motor Drive

There are four types of drive used in electric-locomotive construction and each has certain advantages peculiar to itself:

1 Geared axle drive
2 Geared quill drive
3 Jackshaft and side-rod drive
4 Gearless drive.

1—Geared Axle Drive

As the electric locomotive was the outgrowth of experience in motor-car construction, it was evident that the earliest designs should comprise an operating cab resting on two swivel trucks, a motor being geared to each of the four driving axles. This type of drive has been uniformly successful and is generally accepted today as standard for locomotives where axle weights are not excessive. An example of this type of construction is shown in the C. M. & St. P. 70-ton switching locomotive, equipped with direct-current motors and operating from a 3000-volt direct-current trolley. The same type of construction is also available to single-phase or multiphase alternating-current motors, provided the axle weights in the former case do not much exceed 40,000 lb. The single-phase motor requires more space for a given output and speed than a direct-current motor and is therefore limited in its application to geared axle drive to moderate axle weights, especially if the locomotive must fulfil a service demanding a high continuous tractive effort. This fact accounts in part for the greater favor shown quill and side-rod construction in single-phase-motor locomotives of larger capacity.

Direct-current motors are in successful operation driving through single gears axle weights of 40,000 lb., and through twin gears a maximum of approximately 60,000 lb., as exemplified in Detroit River Tunnel, Baltimore & Ohio Tunnel, and C. M. & St. P. freight locomotives. There are no apparent reasons why twin-geared drive should not prove successful with axle weights exceeding 60,000 lb., although no such locomotives are now in operation. In order that stresses between the two gears may be equalized and to cushion the motor from impact transmitted through the gears from inequalities in the track, it has been found advantageous to interpose a small amount of spring-controlled motion between the gear rims and their centers. This construction in no way resembles geared quill drive as cushion-gear rims are mounted concentric with their centers and in intimate contact with them. The success attending the operation of spring or cushion gears has broadened the application of geared axle drive.

Four-Motor Geared Locomotives. While swivel truck construction, with the draft gear forming an integral part of the cab sub-frames operates entirely successfully with moderate axle weights, it has been considered good practice, in some instances, to introduce articulated-truck construction in heavier locomotives. Good examples of four-motor twin-geared articulated-truck locomotives are presented in the Detroit River Tunnel, Baltimore & Ohio Tunnel, Great Northern, Butte, Anaconda & Pacific, Bethlehem Chili Iron Mines, and Canadian Northern locomotives. The trend of design in the larger locomotives is apparently in the direction of box cabs with an operating compartment in each end.

The maximum speed of four-axle locomotives of the heavier type has usually been limited to approximately 50 miles per hour and no impairment of good tracking qualities has been experienced within this limitation. Undoubtedly higher speeds are permissible with four-axle bogie-truck locomotives, but as yet the limitations have not been fully determined. This type of design is very attractive,

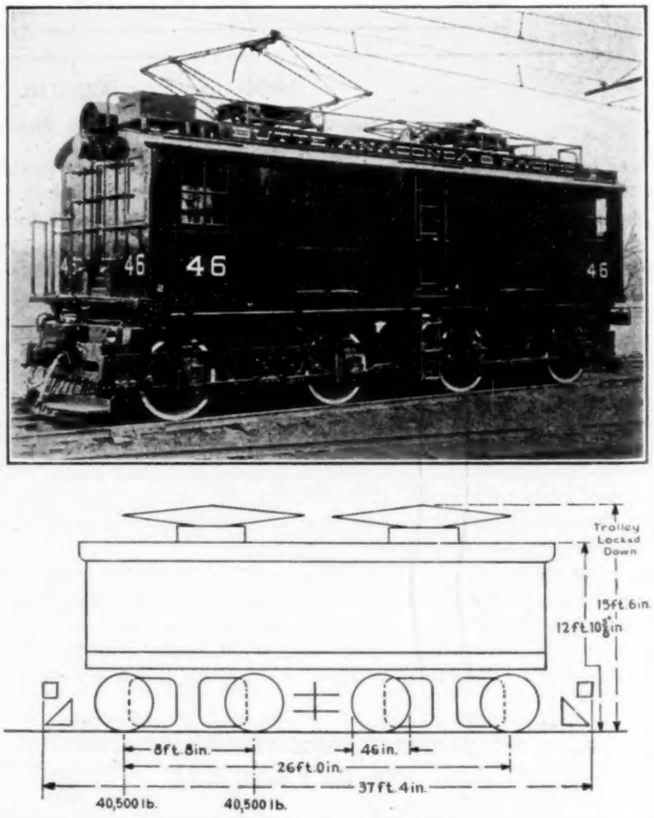
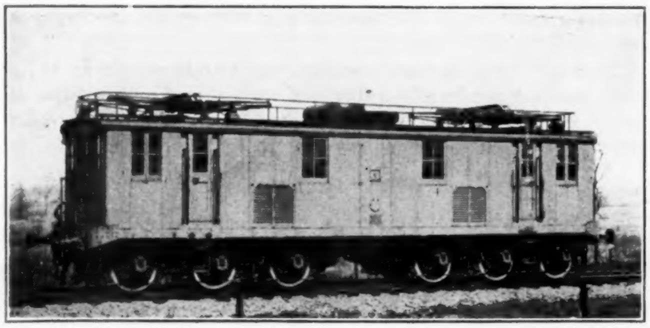


Fig. 5 2400-Volt D.C. 81-Ton Electric Freight Locomotive, Butte, Anaconda & Pacific Ry.

owing to its simple and rugged construction and the opportunity it offers to combine several such four-motor units into one locomotive of any capacity desired. Both from an operating and manufacturing point of view the four-motor swivel-truck locomotive promises attractive possibilities of meeting a wide range of service requirements with but few types of locomotives which could be so generally applicable to average service conditions as to be standardized, a result most earnestly desired by all.



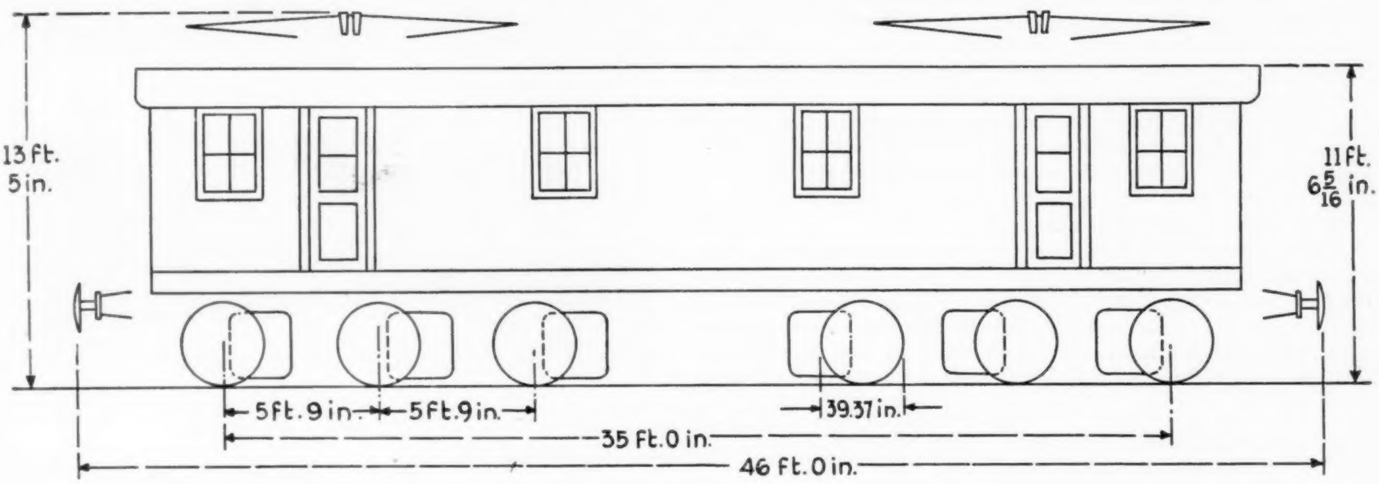


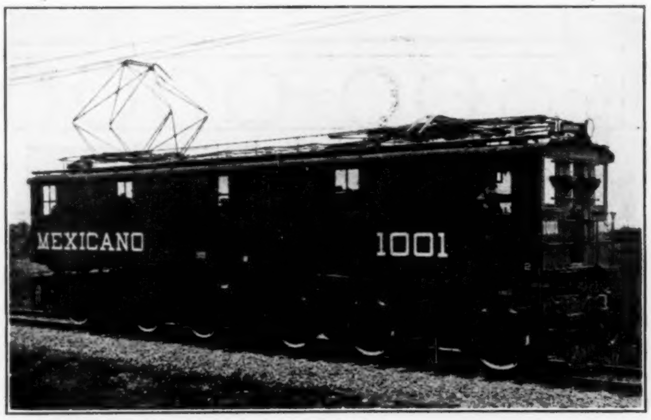
Fig. 6 3000-Volt D.C. 90-Ton Electric Freight and Passenger Locomotive, Spanish Northern Railway

Six-Motor Locomotives. Two locomotives have been built and tested in which six motors are geared to the six driving axles, all the weight of the locomotive being upon the drivers. The wheel arrangement is quite different in the two locomotives and each offers an attractive application of motors geared direct to driving axles of moderate weight.

The Spanish Northern locomotive, weighing 90 tons, has its cab mounted upon two three-axle swivel trucks. The motors are of the direct-current type and operate from a 3000-volt trolley. In this instance the adoption of a three-axle truck permitted the construction of a powerful, compact locomotive having 179,000 lb. total on its drivers without exceeding a weight of 30,000 lb. per axle. It is capable of delivering continuously a tractive effort of 26,500 lb. at 21.9 miles per hour. The Spanish Northern locomotive has just been put into operation and will be used to handle ore trains and incidental passenger service. It is provided with regenerative braking control.

The Mexican Railway locomotive comprises six motors twin-geared to six driving axles arranged in three four-wheel articulated trucks. The cab is supported upon two sub-frames sharing a common center on the middle truck. These sub-frames are of box-girder construction which provides a ready passage through which air is forced to cool the individual motors. In this locomotive the axle weight is 51,500 lb. and the total weight of the locomotive 309,000 lb., all the weight being upon the drivers. Provision is made for regenerative braking. This locomotive has been built and exhaustively tested upon the Erie test track.

Six-axle geared-motor locomotives offer the advantage over four-motor construction of 50 per cent greater capacity, or a lower axle weight to meet special conditions of track and structures or type of motor adopted. Six-motor geared-axle construction is available to



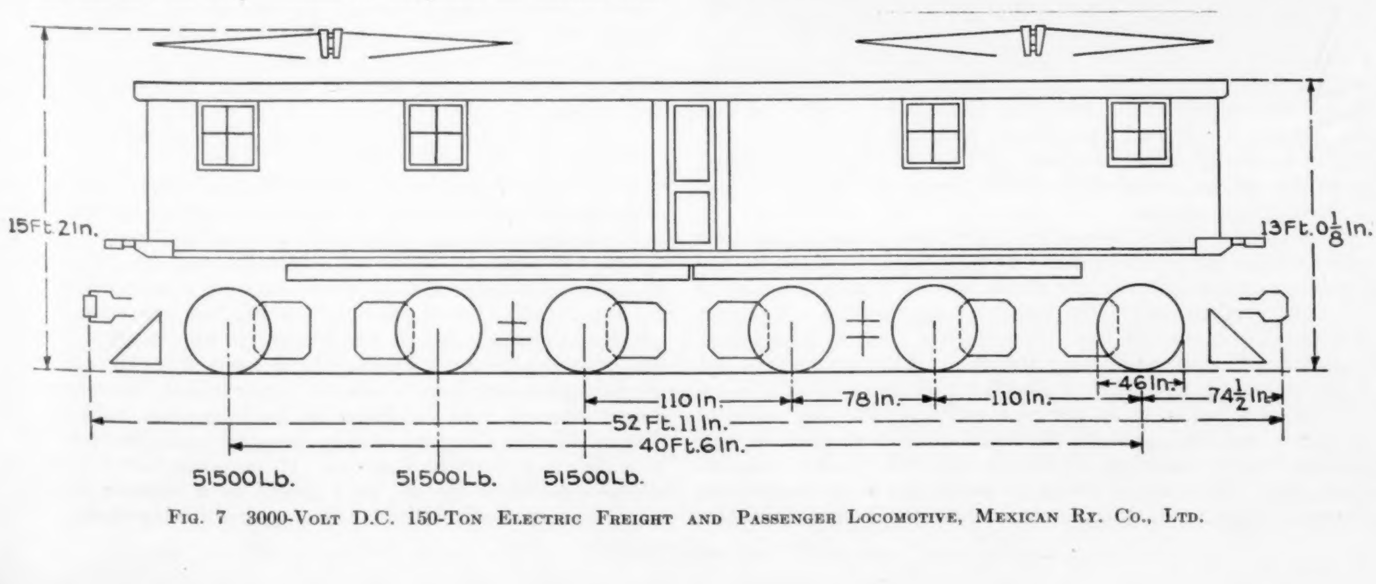


Fig. 7 3000-Volt D.C. 150-Ton Electric Freight and Passenger Locomotive, Mexican Ry. Co., Ltd.

both direct-current and single-phase alternating-current motors with the restriction in the latter type that axle weights cannot greatly exceed 40,000 lb.

Eight-Motor Geared Locomotives. In order to meet the demands for locomotives of very large capacity or to provide for minimum driving axle weight, eight driving motors may be utilized to good advantage. Motors may drive either through single or twin gears depending upon axle weights, and trucks may be articulated or stresses taken through cab sub-frame as desired.

The simplest form of eight-motor locomotive is obtained by coupling two four-motor bogie-truck locomotives together, the eight driving axles being operated as a single locomotive by means of multiple-unit control. Two of the B., A. & P., 81-ton locomotives are thus permanently connected together and operate as a single 162-ton locomotive, under the control of one engineer. Where axle weights and speed are not excessive this type of construction is regarded very favorably by many engineers and operating records attest its reliability and low cost of upkeep.

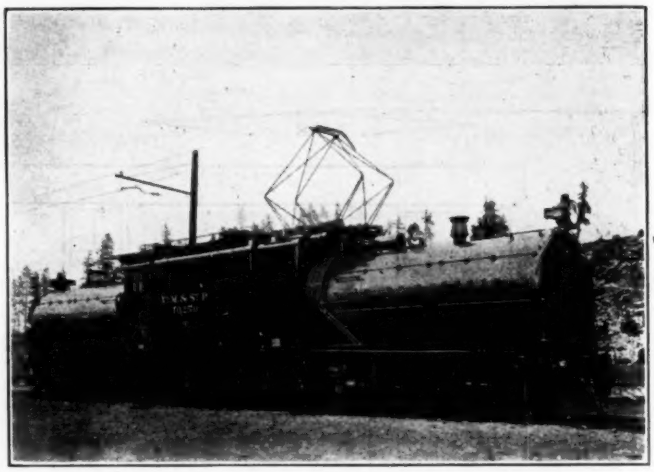
A good example of an eight-motor geared construction is offered in the C., M. & St. P., 3000-volt direct-current freight locomotive which comprises four two-axle articulated bogie trucks and two four-wheel guiding trucks supporting two operating cabs. These locomotives are capable of delivering continuously a tractive effort of 79,500 lb. at a speed of 15.4 miles per hour, and have been in successful operation since December, 1915. The St. Paul locomotive was the first to be equipped with regenerative electric braking, which is now accepted as a desirable addition to electric locomotives operating over mountain grades. As twelve of the St. Paul geared locomotives were originally supplied with high-speed gearing and used in passenger service at speeds up to 60 miles per hour, bogie guiding trucks were added to all locomotives for the sake of interchangeability, although the better tracking qualities thus secured may not have been necessary if these locomotives had been restricted to freight duty only. While an axle load of 60,000 lb. was regarded by some engineers in the past as possibly too high for leading and trailing axles, continued development of both steam and electric locomotives has somewhat modified opinions in this connection. Electric locomotives are in daily successful operation with 60,000 lb. per driving axle and no additional axles, and it is apparent that an eight-motor geared locomotive, weighing 480,000 lb. total, will undoubtedly operate successfully with all weight distributed upon the drivers provided the locomotive operation is restricted to freight-train speeds.

Twelve-Motor Geared Locomotives. The development of this type of locomotive has not proceeded very far owing to the fact that the combined axle weight of eight geared motors is usually ample to meet the requirements of the heaviest freight service. However, it is intended to operate two of the Mexican Railway locomotives coupled together, thus providing 618,000 lb. on the driving axles and a continuous tractive effort of 92,400 lb. Starting effort at a coefficient of adhesion of 30 per cent will reach the high value of 185,400 lb. and this is probably the maximum limit allowable in road engines hauling miscellaneous freight cars with present design of draft gear. There are, of course, no restrictions in the locomotives themselves against coupling in one operating unit even more axles and still greater weight for operation in very special ore train service.

The entire range requirements of freight-train service from light to the heaviest can be admirably met with geared motor drive, and there is every reason to expect this type of construction to hold a preferred position in locomotive design in the future.

2—Gear Quill Drive

This form of construction is more especially favored when single-phase alternating current motors are applied to axle weights beyond the capacity of single motors mounted in conventional manner with geared axle drive. It offers the advantage of supporting all motor weight on springs, high clearance over the rails and permits the use of two motors driving the same gear and thus providing the additional output per driving axle required. The disadvantage of this form of drive has been the spring and wheel-spoke failures in the past due to excessive strains introduced by the difficulty of maintaining the quill reasonably concentric with the driving axle.



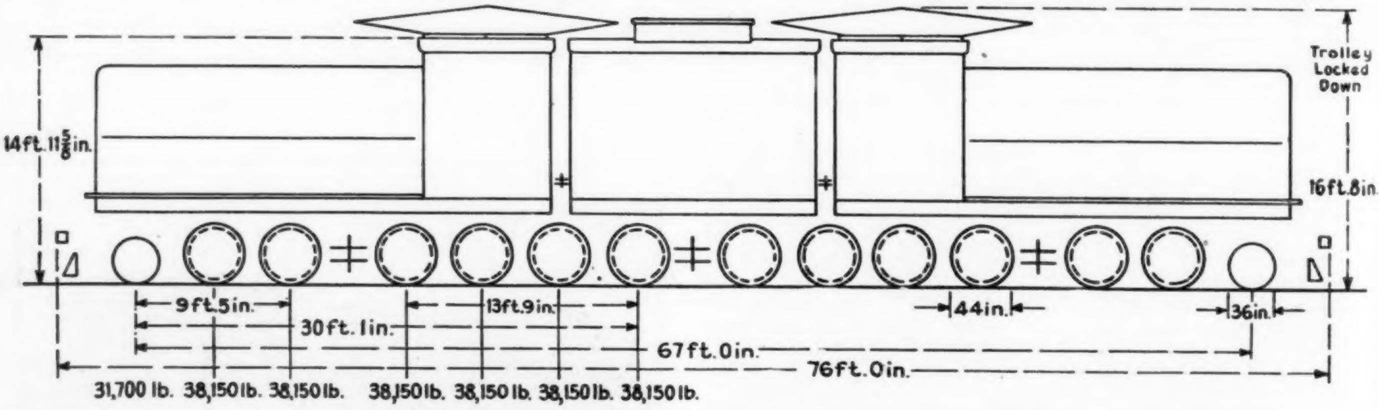
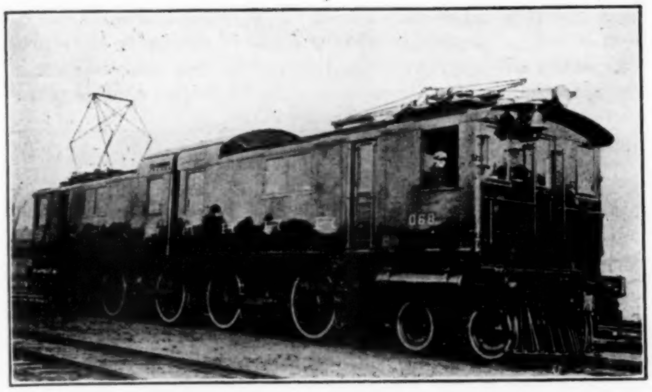


FIG. 8 3000-VOLT D.C. 260-TON ELECTRIC PASSENGER LOCOMOTIVE, C. M. & ST. P. RY.

3—Side-Rod Drive

As with geared quill drive, side-rod drive also offers the advantage of carrying all motor weights on springs, providing maximum clearance between motor and rails, and raising center of gravity of locomotive with whatever better riding qualities may result therefrom. Many forms of side-rod drive have been built experimentally, but not duplicated. Geared side-rod drive, in which one or two motors are geared to the jackshaft which connects with the driving axles through side rods, has apparently been accepted in this country as the most promising form of side-rod construction. An example of geared side-rod drive is offered in the locomotive built by the General Electric Company and in operation upon the New York, New Haven & Hartford Railroad. It comprises four single-phase alternating-current motors, each geared to a separate jackshaft which drives through side rods a single pair of driving wheels. This



France. This locomotive comprises six direct-current motors with armatures mounted directly upon the driving axles and operates from a 1500-volt direct-current trolley. The locomotive comprises two operating cabs each resting upon a three-axle driving truck integral therewith and a hinged four-wheel guiding truck containing no motors. This locomotive is intended for passenger service and was designed with the view of meeting any reasonable speed requirements incident to such service. The tests at Erie, therefore, were carried beyond the contract obligation of successful running at 82 miles and maximum speeds reaching 105 miles per hour were attained, without developing any evidence of destructive action on track. While the complete locomotive is of symmetrical design and provides for double-end running, it comprises two unsymmetrical halves and is equivalent to coupling two Pacific-type steam engines back to back.

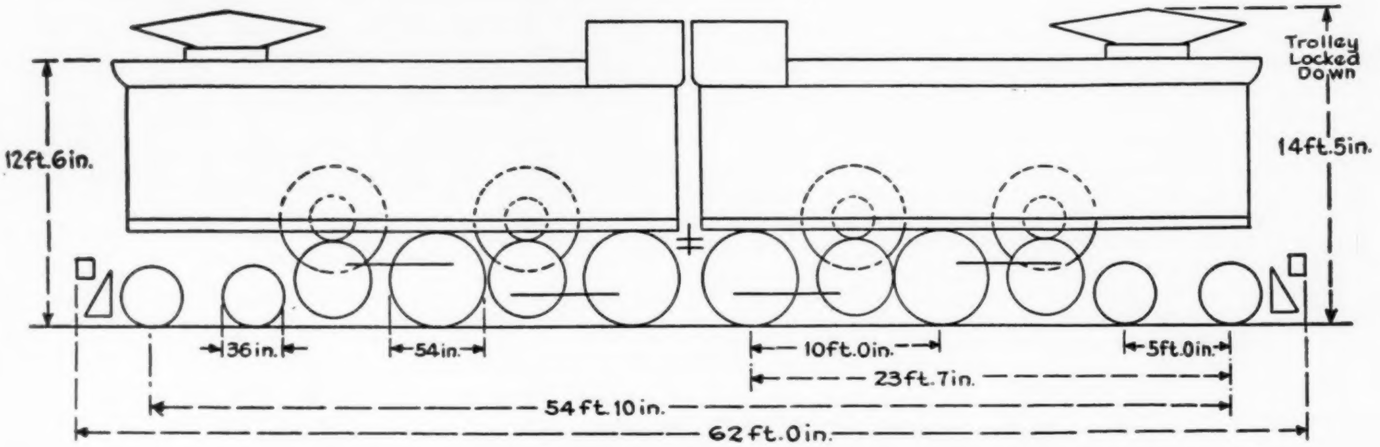


Fig. 9 11,000-Volt Single-Phase A.C. 146-Ton Electric Freight Locomotive, N. Y., N. H. & H. R.R.

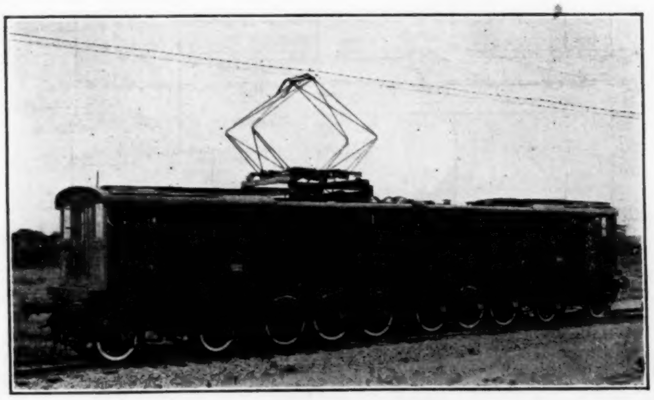
locomotive has a continuous rating of 22,200 lb. at 26.4 m.p.h. The driving axles are supplemented by two four-wheel bogie guiding trucks which assist in carrying the excess weight of motors, transformer and jackshafts, a usual feature of side-rod construction. The reason that side-rod drive was adopted in this instance was because it did not seem feasible to equip a locomotive of this capacity with four single-phase motors geared to the driving axles in the usual way.

Many other forms of side-rod drive and wheel arrangement have been built and apparently the natural development of this form of construction is toward very high driving-axle weights and the addition of guiding axles to support part of the weight of electrical equipment and jackshaft and to provide better riding qualities of the locomotive. Side-rod drive apparently offers greater advantages to the use of single-phase motors than direct-current motors owing to the space limitations of the former when applied to heavy driving axles.

4—Gearless Motor Drive

Another form of six-motor locomotive is illustrated in the Paris-Orleans bipolar gearless locomotive recently built and shipped to

Gearless motor construction provides a maximum of simplicity and efficiency in locomotive design and operation owing to the entire absence of motor and axle bearings, gears, quills, jackshaft, side rod or other means of connecting motors to driving axles used



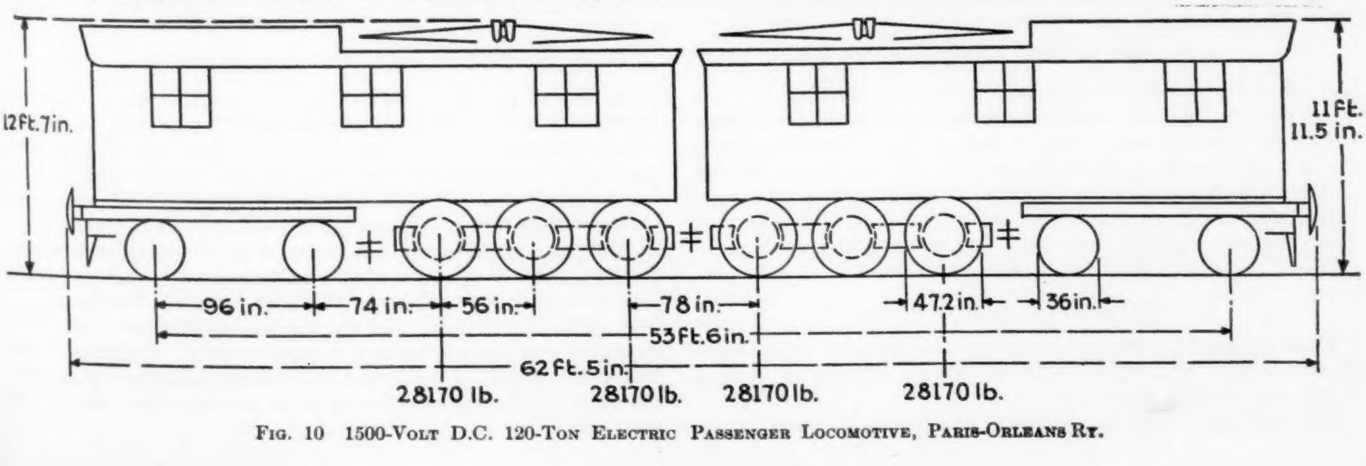


Fig. 10 1500-Volt D.C. 120-Ton Electric Passenger Locomotive, Paris-Orleans Ry.

in other types of locomotives. The first example of the forerunner of this construction was offered in the original Baltimore & Ohio Tunnel locomotive built in 1893. The direct-current motor in this instance, however, was six-pole and was mounted on a quill supported on the driving wheels by rubber cushions. The first example of a modern bipolar gearless locomotive was the S-type construction built for the New York Central Railroad in 1905, 47 of which are still in daily operation. These locomotives comprise four gearless driving axles with a four-wheel swivel guiding truck at each end. A later type of gearless construction utilizing eight motors and all weight on the drivers is shown in the T-type of locomotive of which 28 are in operation. This type of locomotive has a high operating efficiency owing to absence of all driving mechanism and the records of 18 years operation disclose a most attractively low cost of maintenance.

Another example of gearless motor construction is presented in the 3000-volt direct-current passenger locomotives in service upon the Cascade Division of the St. Paul electrification. This locomotive comprises twelve driving axles and two guiding axles, the total weight on drivers being 458,000 lb. This is another example of a symmetrical locomotive composed of two unsymmetrical halves articulated back to back. A novel way of meeting the exacting requirements of boiler installation to heat the passenger train is shown in the heating tender interposed between the two operating cabs. This arrangement gives ample space for a conservatively designed heating boiler and permits the removal of the entire cab in case of necessity. This locomotive provides for regenerative braking.

Gearless motor construction is the simplest form of drive that it is possible to use in the electric locomotive. It offers particular advantages in high-speed passenger-locomotive service owing to its high efficiency maintained over its entire working range, its freedom from speed restrictions, and its adaptability to any wheel arrangement best suited to easy riding at high speeds. The efficiency of the gearless motor is above 90 per cent throughout the greater part of its working range, and this fact holds attractive promise of power economy in operating a service where the low average load factor of a locomotive hauling a fixed load over a broken profile might prove a handicap to other forms of motor drive.

Electric-Locomotive Rating

There are two fundamental factors which determine the tractive-effort rating of electric locomotives—namely, slipping of driving wheels, and heating of motors.

It is well known that the coefficient of adhesion between driving wheels and rails varies over a wide range, depending upon the condition of both. Experimental tests made to determine the starting coefficient of adhesion of electric locomotives has established values ranging from over 40 per cent under almost perfect conditions to as

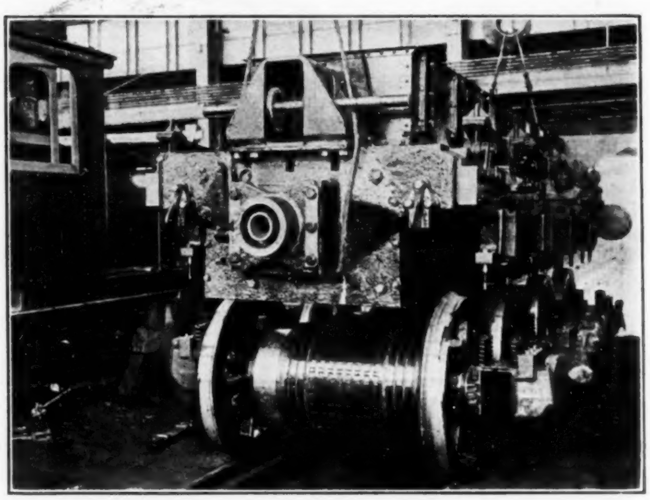


FIG. 11 3000-VOLT BIPOLAR ELECTRIC PASSENGER LOCOMOTIVE, C. M. & ST. P. RY., PARTLY ASSEMBLED

low as 10 per cent or even less when the rails are covered with sleet or snow. By the use of sand, the handicap of poor rail conditions may be partly overcome. Test records of coefficient of adhesion apply, however, only to the local conditions under which they were taken, and it is probably more conservative to accept the general values established in this respect by steam-engine practice on ruling grades. A study of many train-dispatcher's sheets showing trailing and engine tonnage, actually hauled by engines of different types, indicates that the total gross tractive effort exerted at the driver rims amounts approximately to 18 per cent of the total driver weight. Starting effort is in excess of this value and may reach as high as 25 per cent or even 30 per cent under favorable conditions. It is recognized, therefore, that electric locomotives for road service should be capable of exerting a tractive effort of approximately 18 per cent of the driver weight at balanced speeds on ruling gradients and a coefficient of adhesion of 30 per cent when starting the train.

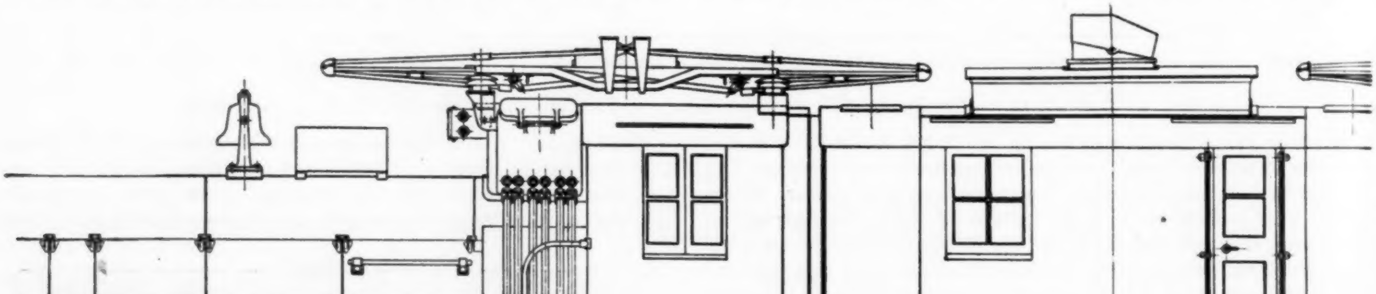


FIG. 12 VERTICAL SECTION THROUGH MOTOR ARMATURES, FIELDS AND AXLES OF LOCOMOTIVE SHOWN IN FIG. 11

While the electric freight locomotives are operated over a wide variety of profiles and service conditions, it is instructive to note the reasonably close agreement of individual tractive effort ratings to the average of 14.06 per cent of the weight upon the drivers. There is more divergence in ratings of passenger locomotives, largely explained by nature of profile, schedule and type of motor, geared or gearless, the latter having a materially greater time lag between load and temperature rise than modern air-cooled geared motors.

Locomotive-Testing Facilities

The designs of steam and electric locomotives up to this time have been largely empirical owing to the absence of reliable tech-

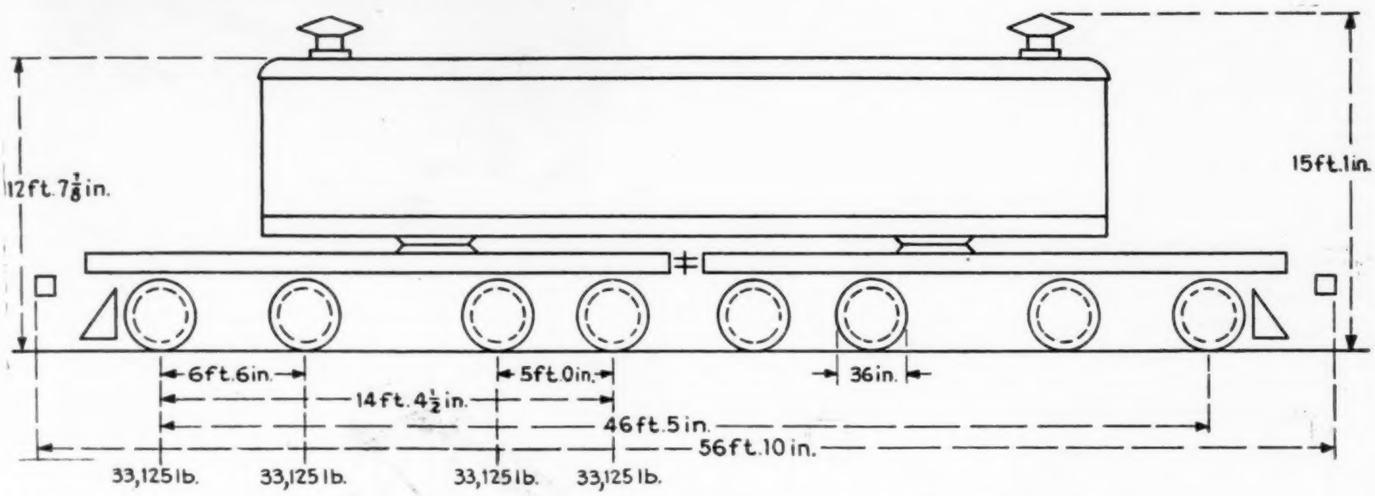
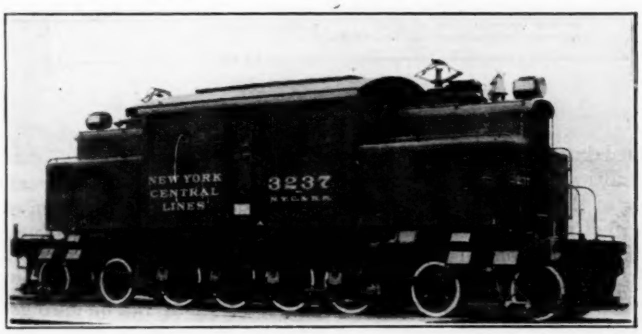


Fig. 13 600-Volt D.C. 133-Ton Electric Passenger Locomotive, New York Central R.R.

The problem of motor construction is to keep it within safe temperature limits and safeguard its insulation. As there is a considerable time lag between load and maximum temperature reached, it is apparent that the duration of the load determines its amount. Hence a motor that may operate continuously at a tractive-effort rating of 16 per cent coefficient of adhesion with a temperature rise of 120 deg. cent., may nevertheless deliver double the output during the short time interval required for starting the train. Hence it is useful to know both the continuous-tractive-effort rating of a locomotive and its rating for short periods of time, especially if it is to operate over a profile of short ruling gradients on which the motors may be properly called upon to deliver more than their continuous rating. For convenience of general comparison the continuous ratings of many of the electric locomotives now in operation are given in Table 1.



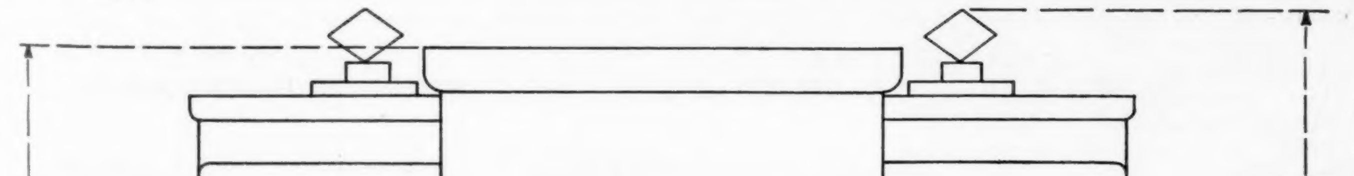


Fig. 14 600-Volt D.C. 122-Ton Electric Passenger Locomotive, New York Central R.R.

TABLE 1 CONTINUOUS-TRACTIVE-EFFORT RATINGS OF ELECTRIC LOCOMOTIVES

(Expressed in terms of driver weight)

	Tractive effort, lb.	Coefficient of adhesion, per cent
Freight		
Bethlehem Chili Iron Mines	35,200	14.7
Boston & Maine	21,000	9.7
Butte, Anaconda & Pacific	25,000	15.6
Chicago, Milwaukee & St. Paul	79,500	17.65
Great Northern	34,800	15.1
Mexican	46,200	14.65
New York, New Haven & Hartford	17,000	10.3
Norfolk & Western	66,000	14.5
Paulista	27,300	13.65
Spanish Northern	26,500	14.8
Average		14.06
Passenger		
Butte, Anaconda & Pacific	15,600	9.7
Chicago, Milwaukee & St. Paul (10,200)	41,000	8.9
Chicago, Milwaukee & St. Paul (10,300)	41,000	12.1
New York Central S-type	5,000	3.55
New York Central T-type	14,000	5.28
New York, New Haven & Hartford (01)	6,400	3.8
New York, New Haven & Hartford (0300)	14,500	6.2
Paulista	13,900	8.7
Paris-Orleans	13,650	8.1
Average		7.35
Switching		
Baltimore & Ohio	13,000	6.5
Canadian Northern	16,200	10.1
Chicago, Milwaukee & St. Paul	14,000	9.8
Grand Trunk	37,000	14.0
Michigan Central	18,000	7.5
New York, New Haven & Hartford (0200)	14,800	9.3
Average		9.53

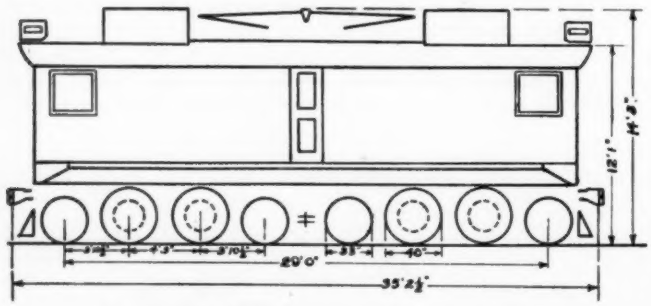


Fig. 15 600-Volt D.C. Electric Locomotive

nical data in respect to riding qualities and impact on rails. Testing facilities have been until recently inadequate for a full understanding of the fundamental principles involved in the construction of a perfect-running locomotive under all conditions. To supplement existing data on this subject there has been built and installed upon the Erie test track an instrument known as the "otheograph," which comprises 25 test ties carrying the running rail on springs in such manner that its deflection is recorded by pencils on paper drums giving 50 vertical and 50 lateral records of impacts of each individual axle passing over each of the 25 ties. A test of a four-axle locomotive therefore makes available 400 records while the locomotive is traversing the 50-ft. distance covered by the test ties. This equipment has been in operation during part of the past winter and spring and has already yielded a number of most interesting and instructive records of different steam- and electric-locomotive runs, and it is expected that careful study of these and succeeding test records will greatly augment present knowledge of the action of different

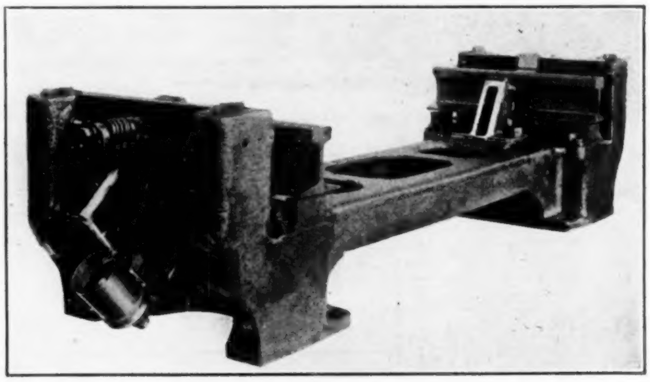


Fig. 16 The Otheograph, a Device Designed for Measuring Horizontal and Vertical Impact Resulting from the Passage of Moving Locomotives or Other Rolling Stock

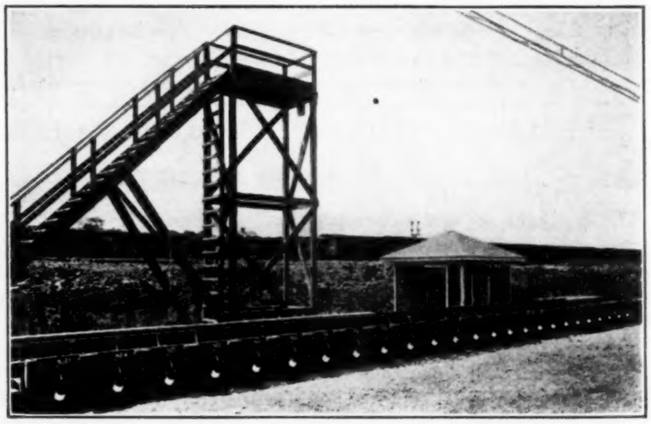


Fig. 17 Otheograph Installation of 25 Units Under the Tracks of the East Erie Commercial R.R., Showing Covers Removed

designs of locomotives upon the track and lead to material improvement in the construction of future locomotives.

Two interesting records accompany this paper—one of the Mexican electric locomotive having the general constants given herein, and the other of a steam engine of the Mikado type. An inspection

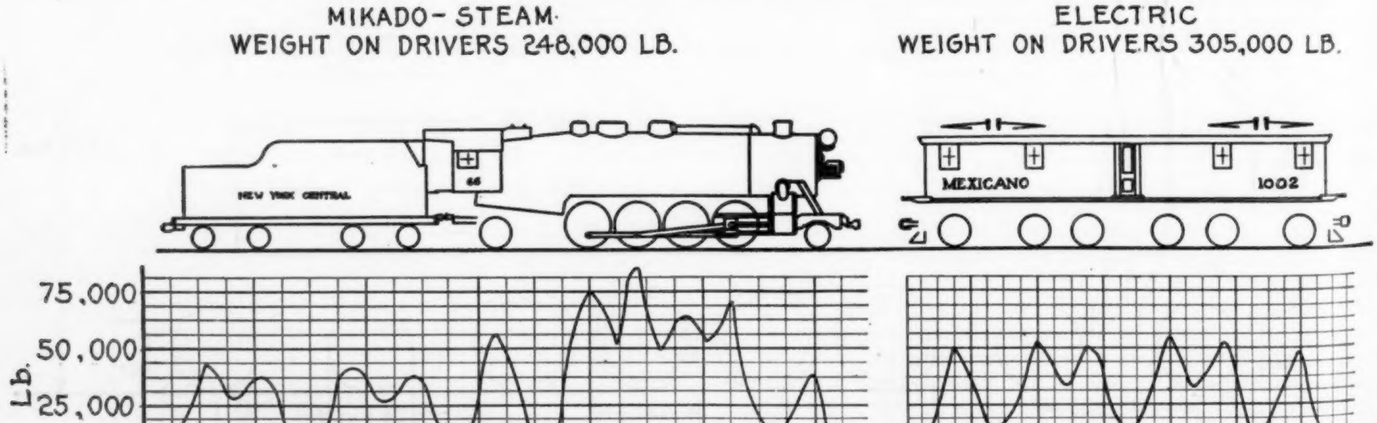


Fig. 18 Otheograph Records of Steam and Electric Locomotives, Showing Vertical Forces on Track at a Speed of 40 Miles per Hour

DATA ON ELECTRIC LOCOMOTIVES FOR HEAVY SERVICE

	Gearless Passenger				Geared Passenger	
	N. Y. C. Type "S" (122-ton)	N. Y. C. Type "T" (133-ton)	C. M. & St. P. Pass. (260-ton)	P-O Pass.	Paulista Pass. (120-ton)	B. A. & P. Pass. (80-ton)
General Data						
Diam. of drivers, in.	44	36	44	47.2	42	46
No. of driving axles	4	8	12	6	4	4
Diam. of guiding wheels, in.	36½	..	36	36	36	..
No. of guiding axles	4	..	2	4	4	..
Total wheelbase, ft.-in.	36-0	46-5	67-0	53-6	46-0	26-0
Width overall, ft.	..	..	..	..	..	..
Length inside knuckles, ft.-in.	43-½	56-10	76-0	62-5 (over buffers)	55-0 (over buffers)	37-4
Height over trolley—locked down, ft.-in.	15-1	15-1	16-8	12-7	14-3	15-6
Ratings	1 Hr. / Cont.	1 Hr. / Cont.	1 Hr. / Cont.	1 Hr. / Cont.	1 Hr. / Cont.	1 Hr. / Cont.
Amperes	2300 / 1060	3000 / 2480	990 / 860	1200 / 1275	460 / 440	392 / 370
Tractive effort, lb.	15200 / 4900	15100 / 11500	48500 / 40800	12750, 11620 / 13650 F.F., 12600 S.F.	14750 / 13900	16800 / 15600
Coef. of adhesion, per cent.	10.5 / 3.3	5.7 / 4.34	10.59 / 8.9	7.54, 6.9 / 8.1 F.F., 7.5 S.F.	9.2 / 8.7	10.4 / 9.7
Speed (full rated voltage), m.p.h.	41.8 / 60.6	54.0 / 59.0	27.1 / 28.7	58.0, 64.0 / 56.5 F.F., 62.8 S.F.	42.8 / 43.4	25.4 / 25.0
Horsepower—driver output	1691 / 792	2180 / 1810	3500 / 3300	1940, 1985 / 2060 F.F., 2100 S.F.	1680 / 1608	1140 / 1040
Max. safe speed, m.p.h.	80	85	90	...	56	45
Tractive effort, 25% adhes., lb.	37,125	66,250	114,450	42,300	40,000	40,250
Weights						
Total weight, lb.	244,500	265,000	521,200	240,000	240,000	161,000
Weight on drivers, lb.	148,500	265,000	457,800	169,000	160,000	161,000
Weight per driving axle, lb.	37,125	33,125	38,150	28,170	40,000	40,250
Mechanical, lb.	184,500	177,000	286,550	137,000	160,300	101,000
Electrical equipment, lb.	60,000	88,000	234,650	103,000	79,700	60,000
Track gage, ft.-in.	4-8½	4-8½	4-8½	4-9	5-3	4-8½
Motors						
Number	4	8	12	6	4	4
Type	GE-84-A	GE-91-A	GE-100	GE-101-A	GE-267-A	GE-229-A
Rated voltage	600	600	1000/3000	750/1500	1500/3000	1200/2400
Method of drive	Direct	Direct	Direct	Direct	Twin Gr-Spr.	Twin Gr-Sol.
Gear ratio	Gearless	Gearless	Gearless	Gearless	70/30 = 2.33	80/25 = 3.2
Ventilation	Natural	Forced	Forced	Forced	Fan on Arm.	Forced
Braking	St. & Aut. Air	St. & Aut. Air	St. & Aut. Air and Regen.	St. & Aut. Air	St. & Aut. Air & Vac. and Regen.	St. & Aut. Air
Control—Type	Type "M"	Type "M"	Type "M"	Type "PCL"	Type "M"	Type "M"
Current Collector	3rd rail & Pantograph	3rd rail & Pantograph	Pantograph	Pantograph	Pantograph	Pantograph

	Geared Freight					Geared Side Rod
	C. M. & St. P. Freight (288-ton)	Mexican Freight (150-ton)	Paulista Freight (100-ton)	Spanish Northern Freight	B. A. & P. Freight (81-ton)	N. Y., N. H. & H. Bull Moose (125-ton)
General Data						
Diam. of drivers, in.	52	46	42	39.37	46	54
No. of driving axles	8	6	4	6	4	4
Diam. of guiding wheels, in.	36	..	..	..	..	36
No. of guiding axles	4	..	..	..	..	4
Total wheelbase, ft.-in.	102-8	40-6	26-8	35-0	26-0	54-10
Width overall, ft.	..	..	..	..	..	10
Length inside knuckles, ft.-in.	112-0	52-11	39-2 (over buffers)	46-0 (over buffers)	37-4	62-0
Height over trolley—locked down, ft.-in.	16-8	15-2	14-3	13-5	15-6	14-5
Ratings	1 Hr. / Cont.	1 Hr. / Cont.	1 Hr. / Cont.	1 Hr. / Cont.	1 Hr. / Cont.	1 Hr. / Cont.
Amperes	960 / 920	750 / 690 F.F., 690 S.F.	460 / 440	440 / 430	392 / 370	1800 / 1600
Tractive effort, lb.	84500 / 79500	51600 / 46200 F.F., 33720 S.F.	28900 / 27300	27100 / 26500	25600 / 23600	27000 / 22200
Coef. of adhesion, per cent.	18.8 / 17.65	16.7 / 14.95, 10.9	14.45 / 13.65	15.75 / 14.8	15.8 / 14.6	13.9 / 11.5
Speed (full rated voltage), m.p.h.	15.25 / 15.4	19.9 / 20.45, 28.0	21.8 / 22.1	21.6 / 21.9	16.6 / 17.0	23.0 / 26.4
Horsepower—driver output	3440 / 3280	2740 / 2520	1680 / 1610	1550 / 1550	1135 / 1070	1650 / 1560
Max. safe speed, m.p.h.	35	...	31.1	34	30	45
Tractive effort, 25% adhes., lb.	112,500	77,250	50,000	44,800	40,500	48,500
Weights						
Total weight, lb.	576,000	309,000	200,000	179,000	162,000	291,000
Weight on drivers, lb.	450,000	309,000	200,000	179,000	162,000	194,000
Weight per driving axle, lb.	56,250	51,500	50,000	29,830	40,500	48,500
Mechanical, lb.	329,000	174,000	120,300	95,000	102,000	172,000
Electrical equipment, lb.	147,000	135,000	79,700	84,000	60,000	119,000
Track gage, ft.-in.	4-8½	4-8½	5-3	5-6	4-8½	4-8½
Motors						
Number	8	6	4	6	4	4
Type	GE-253-A	GE-278-A	GE-267-A	GE-255-B	GE-229-A	GEA-614
Rated voltage	1500/3000	1500/3000	1500/3000	1000/3000	1200/2400	
Method of drive	Twin Gr-Spr.	Twin Gr-Spr.	Twin Gr-Spr.	Sing. Gr-Solid	Twin Gr-Solid	Grd. Side Rod
Gear ratio	82/18 = 4.55	90/18 = 5.0	82/18 = 4.55	72/18 = 4	87/18 = 4.83	71/35 = 2.03
Ventilation	Forced	Forced	Fan on Arm.	Forced	Forced	Forced
Braking	St. & Aut. Air and Regen.	St. & Aut. Air and Regen.	Air Vac. and Regen.	St. & Aut. Air & Vac. and Regen.	St. & Aut. Air	St. & Aut. Air
Control—Type	Type "M"	Type "PCL"	Type "M"	Type "PCL"	Type "M"	.....
Current Collector	Pantograph	Pantograph	Pantograph	Pantograph	Pantograph	Pantograph

of the latter record indicates how valuable the otheograph may become as a means of determining experimentally more exact values of the dynamic augment of steam-engine reciprocating drive, thus indicating the wide application of the new locomotive-testing facilities now made available.

Conclusion

This general discussion of electric locomotives has been more especially devoted to the subjects of wheel arrangement and form of motor drive rather than to types of electrical equipment.

Wheel arrangement is apparently not a matter of much concern in its effect on riding qualities of the electric locomotive for speeds below 50 miles per hour, in other words, the field of the freight locomotive. For the higher speeds incident to passenger-train operation a four-truck construction has found favor on account of its minimum effect upon track and low flange wear.

There are apparently two broad lines being followed in the development of the electric locomotive: first, direct application of the motor to the driving axle and, second, the interposition of jack-shaft and side rods.

Geared axle drive for lower speeds and both geared axle and gearless drive for higher speeds have been so successful in meeting every railroad operating requirement that they may be regarded as accepted standards with direct current motor equipment. The bipolar gearless motor drive is restricted to direct-current motors, but geared-axle drive is available to both direct-current and alternating-current motors provided the axle weight in the latter case does not much exceed 40,000 lb.

Geared quill and geared side-rod drive are favored for single-phase motor application to heavy duty locomotives, as providing the additional space required for the best design of such motors. The latter construction, especially, apparently finds its best expression in very high driving-axle weights and long rigid driving wheelbase, thus possibly restricting the application of such locomotives to roadbeds most favorable for their operation. These same forms of construction are also open to direct-current motor applications, but apparently find little favor as compared to the simpler and more efficient direct axle drive which is employed in nearly every electric locomotive equipped with direct-current motors.

The otheograph installation upon the experimental track at Erie promises to become a most valuable and timely addition to testing facilities hitherto available. The facility with which both vertical and lateral impacts upon track rails can be recorded with any type of steam or electric equipment operating at any speed, should afford opportunity to analyze and better understand the fundamental principles of riding qualities of locomotives and lead to the perfection of future designs.

The new 91.5-ton 2-C-1 single-phase electric locomotive built by Messrs. Brown, Boveri & Co. for the Swiss Railways are designed with individual motors on each driving axle, the gearing being on one end of the axle, the other being free. A single transformer is used located on the four-wheel truck. The locomotive is mechanically lubricated.

Foreign Progress in Cutting Metals

By C. A. BECKETT,[1] NEW YORK, N. Y.

IN A PROGRESS report presented at the Annual Meeting of the A.S.M.E. last December, the Special Research Committee on the Cutting and Forming of Metals stated seven research problems, that if analyzed and carried to their conclusion, would clarify the situation relative to cutting tools. These problems are:

a The development of a standard method for testing tool material and material to be cut

b The development of a standard heat-treating method

c The development of standard tools

d The development of methods for testing tool performance

e The development of a method for testing cutting fluids (lubricants and cooling agents)

f The formulation of a definite basis for a specification of work material, tool material, and cutting fluids

g Experimental research to establish gradually the general and fundamental laws governing the relation between performance (in its several aspects on the one hand and the numerous independent variables on the other), such as the various factors of tool design and adjustment (form and rigidity of tools, side slope, back slope, clearance angles, etc.) speed of work, depth of cut, nature of materials concerned (tool, work and fluid) temperature and methods of lubrication and cooling.

The object of this paper is to show the manner in which the solutions of some of these problems have been attempted by foreign experimenters and refer more specifically to problems *a*, *b*, and *d*.

Heat Treatment of the Tools

In a paper entitled Hardness and Cutting Trials of a Tool Steel,[2] by Dempster Smith and Israel Hey, presented before the Manchester Association of Engineers on March 28, 1924, the authors explain the behavior of tools when taking extremely fine cuts over a wide range of speeds and also the quality and treatment of a tool steel most suitable for use under such conditions.

The tools used were made of A.W. high-speed steel and were given the treatment adopted by the Manchester Committee, which process consists of placing the steel in a smith's hearth, slowly heating it to a temperature of about 800 deg. cent., and then transferring it to a hotter part of the fire and rapidly but uniformly heating it to about 1100 deg. cent., at which temperature the steel may be forged; however, no heavy forging is done after the temperature has dropped to 900 deg. cent.

After forging, the tools are ground (dry) to shape in a tool-grinding machine. They are then placed in a muffle furnace to be preheated to a temperature of 800 deg. cent. and transferred to a high-temperature furnace at 1350 deg. cent., where they remain until the entire surface at the nose is in a state of mild ebolution and the temperature has reached about 1320 deg. cent. The tools are then withdrawn from the furnace and cooled in an air blast.

The tempering process consists of reheating the tools in a muffle furnace at a temperature of about 580 deg. cent. and holding them at that temperature for an hour. In some cases the tools are given a secondary heat treatment at temperatures varying from 450 to 575 deg. cent.

Hardness Determination

It may be recalled that Dr. F. W. Taylor maintained that there was no connection between the hardness of a tool, as generally understood, and "red hardness," and the method he had of determining this red hardness was to subject the tool to an actual cutting test and observe its durability.

Smith and Hey have developed this idea to the extent of actually measuring the degree of hardness by means of time-hardness tests on heated specimens. The experimenters used mild steel for the test, the results of which are shown in Fig. 1. The graph shows a diminution in hardness with increase in temperature up to about 115 deg. cent., and an increase beyond that temperature, but the rate of increase appears to diminish as the temperature rises. It should be noted that this is the first set of experiments conducted along these lines and that it is practically impossible to express an opinion until the experiments have been extended to higher temperatures and until they have been conducted on tool steel.

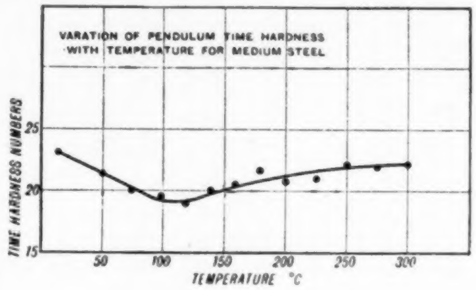


Fig. 1 Variation of Pendulum Time Hardness with Temperature for Medium Steel

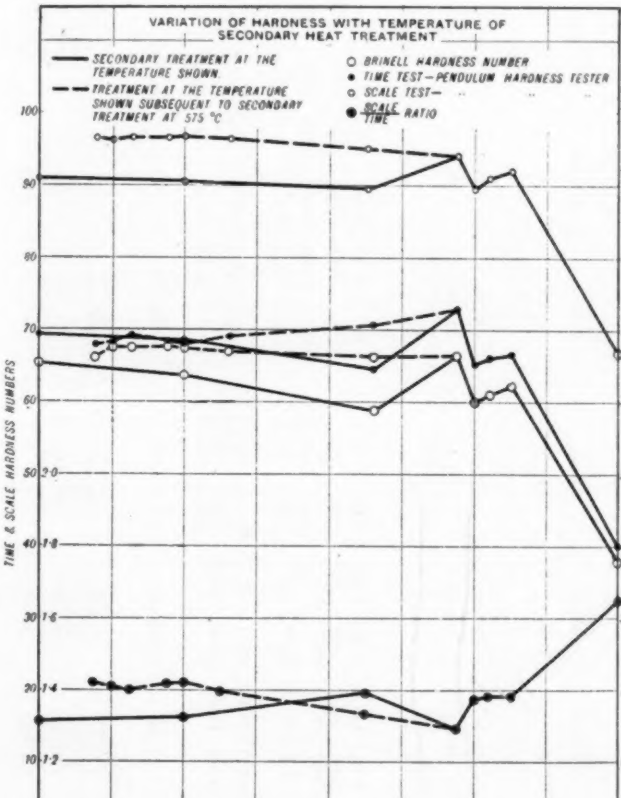


Fig. 2 Variation of Hardness with Temperature of Secondary Heat Treatment

The value of secondary heat treatment is well illustrated in the graph, Fig. 2. The steel used for this test was A.W. high-speed. To quote from the paper:

> The hardness numbers obtained by the Brinell machine and the Herbert pendulum hardness tester are plotted as ordinates on an abscissa of secondary heat-treatment temperature to which the specimens were subjected after hardening. These observations are joined by full lines and were taken in the ascending order of temperature.
>
> The graph of the Brinell values shows a hardness of 644 for a secondary heat temperature of 575 deg. cent., which is slightly higher than that for the steel

[1] Secretary, A.S.M.E. Special Research Committee on the Cutting and Forming of Metals.

[2] Abstracted in *The Engineer* (London), April 4, 1924, pp. 366–368.

Contributed by the Machine Shop Section of the A.S.M.E. for presentation at the Machine-Tool Meeting, New Haven, Conn., Sept. 15–18, 1924.

when quenched out. The hardness decreases slightly as the temperature increases up to about 450 deg. cent. and then rapidly increases up to a temperature of 575 deg. cent. Treatment at high temperatures results in a rapid decrease of hardness up to 800 deg. cent., although there is a slight check in the rate of softening about 600 deg. cent.

The "time" hardness graph agrees with the Brinell results in a most remarkable manner. These together with the "scale" tests, confirm one another and show that a secondary treatment at a temperature of 575 deg. cent. gives a maximum secondary hardness, and that this maximum is reached by first passing through a minimum point at a temperature of about 450 deg. cent. So far the agreement in the character of the Brinell and pendulum

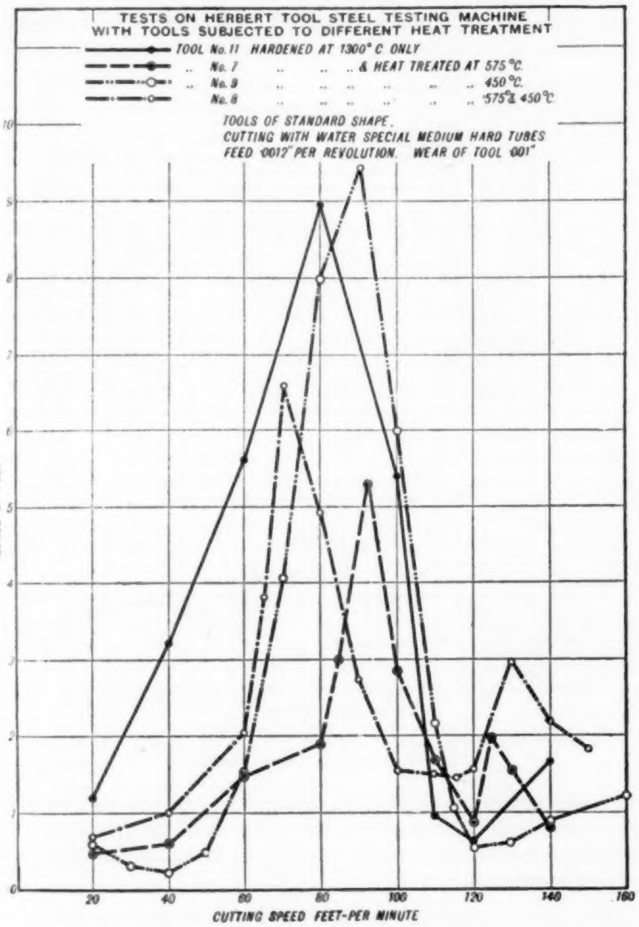


FIG. 3 TESTS ON HERBERT TOOL-STEEL TESTING MACHINE WITH TOOLS SUBJECTED TO DIFFERENT HEAT TREATMENT

tests suggests that for a particular grade of steel hardened and secondarily heat treated at different temperatures, the same physical property which may be turned (hardness is indicated).

In Fig. 2 the dotted lines indicate a Brinell and pendulum observations for hardened specimens of A.W. high-speed steel, subjected to further heat treatments in descending order below 575 deg. cent. after being secondarily heat treated at 575 deg. cent.

Each of the dotted lines shows that any number of subsequent heatings at temperatures below 575 deg. cent. do not appreciably affect the hardness of the steel, that is, a secondary heat treating of 575 deg. cent. establishes a stable condition of hardness up to that temperature for this grade of steel.

THE WORK HARDENING OF METALS

It is interesting to note (see graph, Fig. 2), the manner in which the Brinell and Herbert hardness pendulum tester agree on hardened steel. There is, however, one factor of very great importance that must be considered in connection with a cutting tool, and that is the hardness of the material being cut. In this connection the Brinell does not seem to fulfil the requirements.

A paper presented by A. L. Norbury and P. Samuel on Experiments on the Brinell Tensile Relationship apparently proves this contention. These authors state that the relationship between Brinell hardness numbers and ultimate stresses is well known and widely used in the case of steel. It has, however, its limitations, since different conversion factors have to be used, according to the composition heat treatment and ultimate strength of the steel in question. Moreover, when applied to certain materials it breaks down altogether. On the other hand, the Herbert pendulum hardness-testing machine furnishes a means of measuring the degree of work hardness possessed by a given specimen of metal, provided we know the scale hardness figure for a sample of the same metal which is definitely without work hardness.

E. G. Herbert in describing the pendulum hardness tester and explaining the relationship between the two hardness tests, that is, the scale and time, states that the time test is an indentation test and that the scale test is a working test or a flow test. If one takes a material which is hard but easily worked, such as cast iron one gets a relatively high indentation number and a working number not much higher, the ratio between them being about 1.2 or 1.3. If one takes a material such as annealed high-speed steel, it gives a much lower indentation test (also a lower Brinell), but a much higher working test, as would be expected in a refractory material, and the ratio instead of being 1.2 or 1.3 goes up to 1.9. Manganese steel and rustless iron, both refractory materials, so far as work is concerned, also give an abnormally high ratio between the scale reading and the time reading. This relationship is only put forward as a line of investigation in which nothing is yet proved, but there is a certain inherent probability from the nature of the tests, and also a good deal of evidence to support the view that some indication, if not a measure, of the workability of the material will be given by the ratio of the scale hardness to the time hardness.

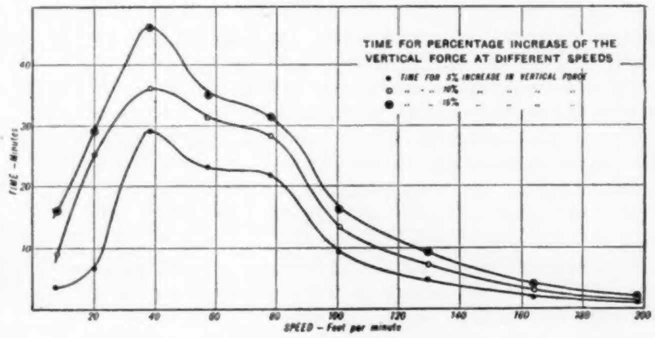


FIG. 4 TIME FOR THE PERCENTAGE INCREASE OF THE VERTICAL FORCE AT DIFFERENT SPEEDS

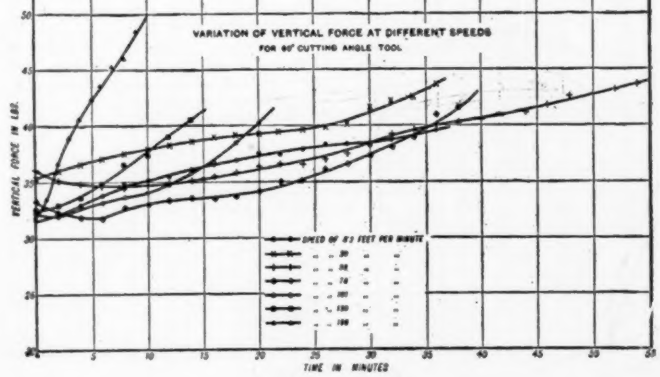


FIG. 5 VARIATION OF VERTICAL FORCE AT DIFFERENT SPEEDS FOR TOOL WITH 60-DEG. CUTTING ANGLE

CUTTING TESTS IN THE HERBERT TOOL-STEEL TESTING MACHINE

In practically all of the experiments that have been carried on in connection with cutting tools, fairly heavy cuts at high speeds have been used, and this has had the effect of raising the temperature to such a degree as would call for the red-hardness property of the steel. Smith and Hey in their cutting trials used the Herbert tool-steel testing machine, where an extremely fine cut could be obtained over a fairly large range of speeds, with the object of determining the variation in durability with cutting speed when taking fine cuts where the tool is probably not raised to such a high temperature. Quoting from their paper:

This machine resembles a drilling machine in form. The spindle carries the work to be operated upon, which takes the form of a steel tube 18 in. long, $^3/_4$ in. in external diameter, and $^1/_{16}$ in. thick. The tool is held in a vise

situated below the tube and the end of the latter is kept in contact with the cutting edge of the tool by means of weights placed on the spindle sleeve, but the feed is prevented from exceeding 0.0012 in. per revolution. Speeds up to 180 ft. per min. are obtained by a small electric motor operating through a four-speed gear box and a variable-speed friction drive. An autographic record of the amount of tube cut away for a predetermined amount of wear of a cutting edge of the tool is given on a drum which rotates at a rate proportional to the speed of the spindle. The test proceeds until wear of the cutting edge allows the tube to touch a ball situated 0.001 in. below the original level of the cutting edge.

The inches of tube cut away during the test are plotted against a corresponding speed in Fig. 3. The trials run were made on medium-hard steel tubes with four tools of A.W. high-speed steel heat treated as follows: No. 11, hardened at 1300 deg. cent. only; No. 7, hardened 1300 deg. cent. and heat treated at 575 deg. cent.; No. 9, hardened at 1300 deg. cent. and heat treated at 450 deg. cent.; No. 8, hardened at 1300 deg. cent. and heat treated at 575 and 450 deg. cent.

The difference noted is that the amount of tube cut away increases with an increase of speed up to a certain value and then decreases rapidly, but again increases slightly at speeds between 120 and 140 ft. per min. This is totally different from the results obtained when taking heavy cuts on steel where the life of a tool invariably increases as the speed decreases.

Because of the peculiar character of the graphs, Fig. 3, another series of tests were made, using an ordinary lathe which was of the standard type with an all-geared headstock and single pulley drive. An additional set of wheels was added to the gear train in order to get a traverse of 0.0013 in. per revolution of the work and thereby approximate the traverse of the Herbert tool-steel testing machine.

The shape of the tools used in this series of trials differed from those ordinarily used in that they were ground to a side cutting angle of 60 deg. (no front top rake) with a front and side clearance of $1^1/_2$ deg. and a front-top clearance of 3 deg. The corners of the tool which engaged the bar were always kept square, that is, no nose radius. The tools were set up with the cutting edge in a horizontal plane, and in line with, and at right angles to, the axis of the test bar.

The difficulty which immediately presented itself was the fixing of a standard of wear or measure of durability of

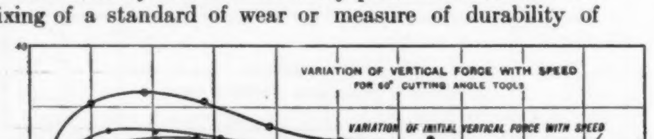


Fig. 6 Variation of Vertical Force with Speed for 60-deg. Cutting Angle Tools

performance. The Herbert tool-steel testing machine adopted 0.001 in. wear of the cutting edge, but to do this in a lathe it would be necessary to employ devices that would sacrifice the rigidity sought. Quoting from Messrs. Smith and Hey's paper:

> Results have been advanced on different occasions to show that the vertical force on a tool for a compact shaving remains practically constant at all speeds. Having this in mind, it was thought that by providing a sensitive arrangement for measuring this force, the work done for a certain percentage increase of the intial force would afford a suitable standard.
>
> When a certain percentage increase of the initial force is taken as a measure of performance, the curves shown in Fig. 4 are obtained. The percentages shown are 5, 10, and 15. The character of the three curves is alike, and it was decided to take a value of 10 per cent increase on the initial force as a measure of performance for all subsequent durability trials. With a 10 per cent increase in the initial force the tool is worn away about 0.0015 in.

For the purpose of measuring the vertical force during the cutting process with a tool taking fine cuts, a force dynamometer was designed to fit the turret of the lathe. The force on the tool was balanced by a weight on a steelyard with a graduated scale. The yard was free to float between stops carried on a bracket from the turret. The turning effort due to the tool and holder was balanced by a separate adjustable weight on an arm beneath the steelyard. When in use this type of dynamometer is very sensitive, a movement either way of 0.10 in. of the weight along the scale being sufficient to bring the lever against the stop.

Variation in the Vertical Force with Speed of Cutting

A series of preliminary trials on medium steel when cutting without a cooling medium was undertaken at various speeds in which

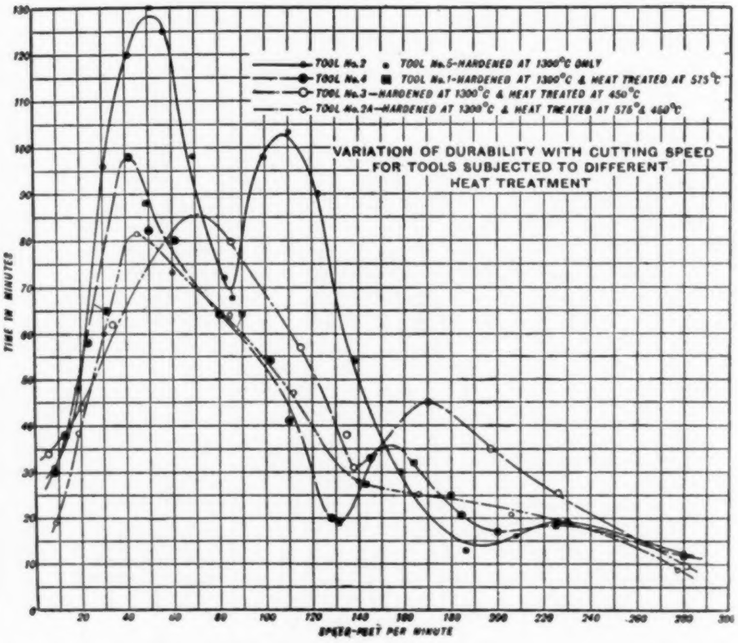


Fig. 7 Variation of Durability with Cutting Speed for Tools Subjected to Different Heat Treatment

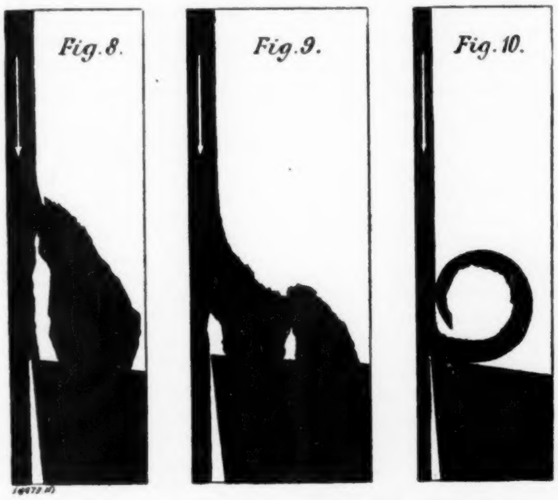
the force excerted on the tool was observed as the cutting progressed. This trial was conducted for the purpose of determining if the vertical force on moderately heavy cuts remains constant at all cutting speeds.

> The results of these trials are shown in Fig. 5, where the cutting force is plotted as ordinate on an abscissa of time and different shapes of spots are used to indicate the tests made at different speeds. These tests were made with a tool of steel inferior to that used in the later durability trials, but repeated experiments with standard A.W. tools revealed the same characteristics. The value of the initial force is seen to vary as is also the rate of increase of the vertical force with speed of cutting.
>
> With regard to the latter, it is shown that for speeds of 8 and 20 ft. per min. the force gradually increases with the time of cutting and after 30 min. the rate of wear at 20 ft. per min. considerably increases, but at the speed of 8 ft. per min. the accelerated rate of wear is delayed. A peculiar feature of these trials is that between speeds of 40 and 100 ft. per min., the force gradually diminishes at the commencement of the trial and afterward increases. The diminution of the force in the early stages is due to a grooving of the upper face of the tool. At speeds above 100 ft. per min. the diminution of the force is not apparent, but the force increases rapidly from the commencement of the trial.
>
> The value of the initial force at different speeds shown in Fig. 5 has been reproduced in the uppermost curve of Fig. 6 in order to show how this force varies with the speed of cutting. This change in the force with speed is not due to any change in the initial sharpness of the tools, variation in depth of cut, or other controllable conditions in the trials. The further trials with tools Nos. 2 and 4 having a 60-deg. cutting angle—shown in the lower curves of Fig. 6—support these observations. These were obtained by taking a fresh tool and observing the force at the lowest speed and each successive increase of speed up to 160 ft. per min. without withdrawing the tool. On reaching the latter stage the tool was reground and the test repeated in the reverse order of speed. Completing the series without withdrawing the tool insured a uniform depth of cut throughout. The cutting time taken for a complete set of observations was about five minutes, so that the blunting effect would be small.
>
> The frictional resistance of dry metal surfaces in contact diminishes as the speed of rubbing increases, although not in direct proportion, and this would result in a diminution of the vertical component of the frictional force acting upon the top face of the tool with a corresponding diminution in the vertical force. Experiments with a 90-deg. cutting angle tool, however, showed that

the effect due to shaving friction was small, and consequently the shape of the curve is not altogether due to friction.

An examination of the shaving shows that at a speed of 8 ft. per min. the shaving spreads broadwise and is uniform in thickness. With increase in speed up to about 100 ft. per min. the shaving spreads at the outer edge and is tapered in section, but as the speed is further increased to 200 ft. per min. the shaving again spreads to the width attained at the low speed.

An examination of the tools shows that at low speeds there is considerable rubbing at the corner and front face, but this diminishes as the speed increases and at the high speeds the pressure of the cut causes the metal of the tool to flow and accentuate the grooves in the upper surface.



Figs. 8, 9 and 10 Three Types of Chips

Durability Trials with Hardened Tools Subjected to Different Subsequent Heat Treatments

The results which were obtained in these ex periments are shown in Fig. 7 (page 620) where the time for the tool to obtain a 10 per cent bluntness is plotted as ordinate on a base of speed. The cut which was taken in all cases was 0.0625 in. deep by 0.0013 in. traverse, and no cooling medium was used.

The medium steel operated upon was of the following composition: Carbon, 0.35; silicon, 0.15; manganese, 1.04; sulphur, 0.05; phosphorus, 0.04. The results, like those obtained in the Herbert tool-steel testing machine, see Fig. 3, show that the durability does not continually diminish with increase in speed such as obtained in trials with heavy cuts. For a fair comparison of the results obtained in the two cases the volume of metal removed during the period required to produce the standard bluntness rather than the simple length of this period must be contrasted with the "inches of tube" cut away in Fig. 3, but it must be noted that the former trials were made without the use of cooling medium, while the latter had a strong stream of water playing on the tool face. Again, the material in the latter trials was considerably harder.

A detailed examination of the results shows that for the lower speed the hardened tool only gives the best results, but the relative performances of the tools do not correspond. Lest any mistake had been made in the heat treating of the tools or an accident had occurred during the test, trials were made with fresh tools to check the results obtained at critical points. These are shown by the square spots in Fig. 7 and confirm the previously obtained data in a most remarkable way. It is apparent that for such light cuts there is little to be gained by giving the tools a secondary treatment, as the temperature to which the tools are raised does not bring into play the red-hardness quality of the steel except possibly at the higher speeds.

From the force trials, illustrated in Fig. 6, it is seen that the force is least at the slowest speed, which indicates that the material being cut offers the least resistance. At the same time the tool is in its coolest condition, yet the durability is extremely low. It is difficult to imagine that the tool would offer a higher resistance to abrasion when hot than when it is cold, although the resistance at 500 deg. cent. may be greater than that at 300 deg. cent.

Mr. Herbert, in summing up the work done by Messrs. Smith and Hey, draws the following conclusions:[1]

a Certain steels in the unhardened state exhibit a marked decrease in their capacity to work-harden at a range of quite moderate temperatures. Within that range they are not only much easier to work, but are less destructive to the tools used to work them. Whether this remarkable phenomenon is common to all varieties of steel or whether it occurs in non-ferrous metals has yet to be determined. Temperature work-hardening determinations are not difficult to carry out with a pendulum hardness tester and special appliances have been designed to facilitate the process.

b A tool used for cutting metals attains a maximum durability when the cutting conditions are such as to raise the temperature of the work to the critical range where its work-hardening capacity is at a minimum.

c A cutting tool usually exhibits a second maximum durability, which is assumed to be due to further changes, the nature of which is not yet known, which occur either in the tool or in the metal operated upon a range of temperatures different to the first.

d To ascertain whether a tool will possess great durability under cutting conditions which generate high temperatures, it is useless to apply any tests to it in its cold state. The utmost utility of such tests is to eliminate tools which are either soft or overhard.

e The fact that a tool retains its hardness at high temperatures may or may not be conclusive evidence that it will be durable at high speed or under heavy cuts, but if the tool can be shown to become soft at such temperatures this is conclusive evidence that it will not work under cutting conditions which generate high temperature.

f An adequate knowledge of the working properties of tools and of work materials can only be obtained by testing them hot.

The National Physical Laboratory at Teddington, England, is at present conducting an investigation to better determine the behavior of mild steel and brass under cutting tools. The conclusions of this inquiry have yet to be formulated, but the photographs shown at the British Empire Exhibition disclose evidence of the distortion that as yet has not been generally recognized, and still has to be explained and applied. Quoting from *Engineering* May 16, 1924:

Fig. 11 Photomicrograph of Brass Chip in Process of Formation

Fig. 12 Photomicrograph of Mild-Steel Chip in Process of Formation

Fig. 13 Photomicrograph of Brass Chip in Process of Formation

The method used has been to rotate the work, a disk, by hand against a stationary tool, thus developing a chip without detaching it. The disk having then been taken off the lathe, a sector containing the chip has been cut out, embedded electrolytically in copper, ground down, polished and etched. Figs. 8 to 10 are drawings made by optical projection, showing on a magnified scale three types into which the chips have resolved themselves. Fig. 11 is a photomicrograph of a brass chip of the type shown in Fig. 10 in

[1] Influence of Temperature on the Work-Hardening of Metals, E. G. Herbert, *The Engineer* (London), April 4, 1924, pp. 356–357.

which the cutting action is seen to be accompanied by a remarkable zone of deformation in the neighborhood of the tool. Figs. 12 and 13 show pieces of such chips in mild steel and brass, respectively, much more highly magnified, showing the distortion even more plainly. Whether further examination will produce the required explanation and application—what relation circumstances such as rake and relief of the cutting tool and the physical properties of the metal cut may bear to the formations here disclosed, and where the chips formed at ordinary cutting speeds will have any, and what, relation to these—are questions that doubtless are not answered by the present exhibit, but it indicates that the laboratory is throwing new light on an old subject by an original method.

Machine-Tool Testing Laboratory of the Technical Institute, Berlin[1]

The Machine Tool Testing Laboratory of the Technical Institute in Berlin has for its purpose not only scientific testing but also the handling of practical problems submitted to it by the industry. In its testing work it is attempting to determine the performance of machine tools not only from the point of view of efficiency but of technical output. Tools, cutters, etc., are tested from the point of view of quality of product, material, and precision of working under normal conditions and in rush work. Facilities are also available for testing such auxiliaries as belts, lubricants, coolants, etc., and for testing the machinability of raw materials and intermediary products.

As regards the measuring instruments employed, some are built into machines permanently, while others are detachable. The principle of installation of all machine tools in the laboratory is that the unit must be capable of being used either as an element in a test or as an actual producing machine.

As an example the equipment and methods used for testing, lathe work may be taken. The test stand of the lathe is provided with a quadruple registering device. As would appear from Fig. 14, the advantage of this construction lies in the fact that the paper on which all the four pens leave their traces is carried over a stationary table and its forward motion is automatically effected by means of a needle roll, while all the other rolls, such as those governing the supply and rolling up of the paper and the pulling roll are entirely independent of the drive. Furthermore, the collector roll is located outside the apparatus proper, and permits removal of the paper with the record at any desired time. The forward movement of the paper is controlled by the drive shaft and is therefore always proportional to the duration of the cut, and proceeds at a rate varying as the change of the cutting velocity during the test. It is adjustable in the ratio of 1:2:3.

All the work of the installation of the apparatus, together with the changes in the indicating manometers which the application of the registering device required, was carried out partly in 1913 and partly in 1914 to 1915. It was found that for the purpose of forming a comparative opinion as to the cutting performance, a chip having a cross-section of only 5 × 1 mm. (0.2 × 0.04 in.) was sufficient. See Fig. 15.

Since the measuring supports of the device were sufficiently sensitive to handle both the light cuts as well as heavy cuts measuring over 100 sq. mm. (0.155 sq. in.) in cross-section, it was necessary to provide that the registering apparatus should also work within these limits.

In general, in the case of measuring-nozzle apparatus it is very difficult to change manometers, but in this case it was necessary for this to be possible in order to carry out the various features of the tests intended. Therefore, in installing the registering device on the lathe test stand, as well as in installing the registering devices on other machines, such as the experimental boring mill, it became necessary from the start to provide means for exchanging manometers and for installing the various devices necessary for this purpose. There were available for the installation on the experimental lathe three kinds of registering manometers with pressures, respectively, of 60, 25, and 12 kg. per sq. cm. (850, 355 and 171 lb. per sq. in.), and two sets of manometers for the experimental boring mill, with pressures of 12 and 4 kg. per cm. (171 and 57 lb. per sq. in.). It may as well be stated here that the reconstruction of registering manometers can be carried out without disturbing the calibration only if certain rules are observed in the strictest manner and that, strictly speaking, a separate calibration should be carried out for each connection of the nozzle with a part of the system.

For the control of the material during individual cuts there has been installed on the rear of the stand a ball-pressure press of peculiar construction driven by a double-acting screw pump built by Amsler. Next to this press a scleroscope is installed in such a manner that it can be swung out of the way of the chip during cutting. With these two devices, it is possible to undertake not only tests of each layer of the material as cut, but, if necessary, the control of the material continuously both before and after the cut. It would appear, however, that it is hardly necessary to undertake such an extensive control of material in the case of the shafting hitherto used in the laboratory for tests on machine tools, and made from extremely well-forged stock by one of the best local steel companies. As a rule, it is sufficient to control the material layer-wise and at three points (both ends and middle) on the shaft, particularly as the measuring devices indicate clearly all sudden variations, such as steel chips welded in a piece of cast-iron shafting. Of still greater importance is the determination of correct sharpening of the cutting tools. The control of this is carried out on a measuring device illustrated in the original article and built in 1914 in the laboratory itself (in accordance with the designs of Schlesinger-Kurrein). By means of this device the position of the cutting edge with respect to the axis of the rotation is determined in the horizontal and vertical planes and the angle is determined in a plane located at right angles to the cutting edge.

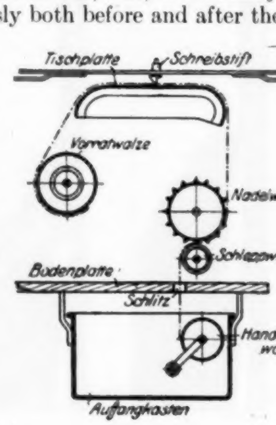


Fig. 14 Diagram of the Arrangement of Registering Device and Paper Movement

(*Tischplatte* = table; *Schreibstift* = pen; *Vorratwalze* = roll carrying supply of paper; *Nadelwalze* = needle roll; *Schleppwalze* = pulling roll; *Bodenplatte* = bed plate; *Schlitz* = slot; *Handkurbelwalze* = hand crank roll; *Auffangkasten* = receiver case.)

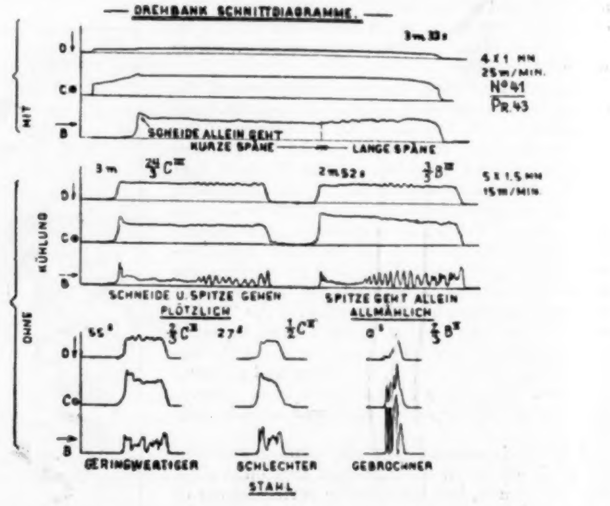


Fig. 15 Diagram of a Cutting Test on the Experimental Lathe

(*Ohne* = without; *mit* = with; *Kühlung* = cooling; *kurze Späne* = short chips; *lange Späne* = long chips; *plötzlich* = suddenly; *allmählich* = gradually; *Stahl* = steel; *geringwertiger* = low-grade; *schlechter* = poor; *gebrochner* = broken.)

The paper describes further in a manner somewhat similar to the above the methods of testing of boring mills and shapers and the methods of investigating belts, lubricants, and experimental transmissions. It also describes how certain problems of practical interest submitted to the laboratory were handled. Among these may be mentioned the machining of light metals, such as magnesium and aluminum alloys. An appendix gives a somewhat more detailed description of the laboratory itself, showing the floor and basement plan, and photographs of some of the tools and test stands.

[1] Abstract of paper by Dr.-Ing. G. Schlesinger and Dr. M. Kurrein in *Berichte des Versuchsfeldes für Werkzeugmaschinen an der Technischen Hochschule, Berlin*, no. 7, 1924, 22 pp., 10 figs.

Testing Machinability by Drilling

The resistance which a metal offers to machining by cutting tools, according to a joint investigation of Prof. Drs. Kessner and Heyn, depends not only on the hardness but also on the plasticity of the material. Quoting from a paper by the former in the April, 1924, issue of *Testing:*

Hardness has been defined as the resistance which a body offers to the penetration by another, harder body. Plasticity is the ability of a body to undergo dislocation of its smallest structural particles, as a consequence of the application of external forces, at ordinary temperatures, without disturbance of their coherence. The resistance which a material offers to penetration by a cutting tool is due to its hardness and plasticity; the "machinability" of the material depends upon the combined effect of these two characteristics.

For determining the resistance to penetration by cutting tools, the author devised a drilling testing machine. In this a numerical value for machinability is established by using a drill as a cutting tool and measuring the drilling depth obtained by 100 revolutions of the tool. The test is based upon the consideration that for a definite load the depth of drilling obtained by a definite number of revolutions may be greater in proportion to the better machining qualities of the material under investigation.

The recording pencil automatically draws a diagram the ordinates of which are the number of revolutions of the drill and the abscissas are drilling-depth values. If the material under investigation is homogeneous and its thermal conditions remain constant, the autographic record will be a straight line. The angle α which this line forms with the horizontal (Fig. 16) is a measure of the machinability of the material under test, and material A is seen to be twice as difficult to machine as material B.

Material C shows a hard spot at h and material D a soft spot at w, while material E becomes harder toward the inside and material F softer. In the curve G, the curvature r represents the initial attack of the drill, i.e., the vertical travel which must be traversed in every test until both cutting edges of the drill are in effect over their entire length.

The angle of inclination of the straight record line or of the straight line drawn to connect the starting and end points of the curves represents the value of the machinability of the material. Since, however, the measurement of this angle may introduce an error, the actual depth of the hole drilled by 100 revolutions can be taken as measure of this property (assum-

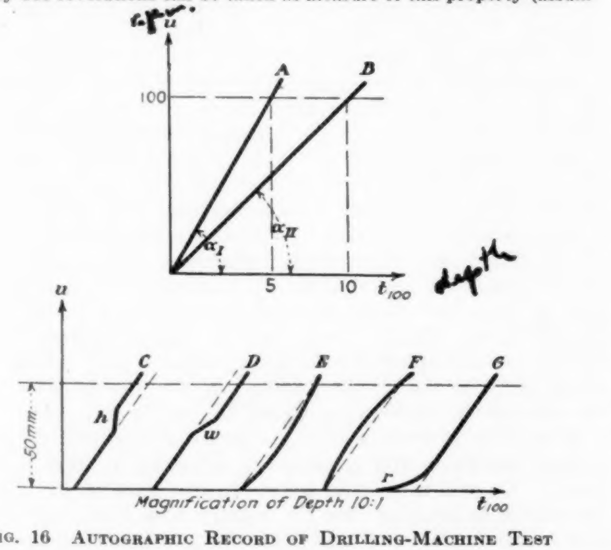


FIG. 16 AUTOGRAPHIC RECORD OF DRILLING-MACHINE TEST

ing that all external conditions such as load on drill, revolutions, diameter of drill, cutting edges and all angles, remain constant).

The drilling testing machine is described in the original article together with certain investigations carried out by means of it, such as ball penetration and machinability of brass with increasing lead content; influence of silicon content on the machinability of cast iron; influence of speed of cooling on machinability and ball-penetration hardness of cast iron.

Since the drilling test does not yield absolute values but only comparative ones, the author endeavored to find by means of an extended series of tests a metal which would serve as a standard of comparison to which other metals could be brought into relation.

For individual shops it is sufficient if they take as standard of comparison any homogeneous alloy they please that is easily accessible in fairly large quantities, and if they calculate all drilling tests on a basis of comparison with that particular alloy. The particular alloy chosen may again be compared from time to time with rolled and annealed electrolytic copper, so as to bring the shop tests into relation with tests made in scientific research institutions, which would use the latter material. In the numerous tests undertaken in the laboratories of the Deutsche Maschinenfabrik A. G., a "hollow drill steel" of the following analysis was used for the purpose of a comparative standard: C, 0.85; Si, 0.05; Mn, 0.26; P, 0.035; S, trace. This material had a Brinell hardness of 207 at 3000 kg. load on a 10-mm. ball.

Fig. 17 shows numerically and graphically values of ball-penetration hardness and machinability of a number of metals and alloys. The various materials are arranged according to their ball-penetration hardness, starting with the hardest metal investigated. Against these hardness values—shown at the left—the values of machinability expressed in their ratio to that of copper (taken as unit of 1) are shown at the right. This graphic representation shows, for instance, machine steels of different strength and hardness and verifies the statement previously made that of two metals of equal strength the one possessing greater ductility is that which is the more difficult to machine. The particularly ductile metal copper, with a hardness of 110 kg., was taken as a comparative standard and its machinability to be unity. Nearly all the other metals investigated were easier to machine than copper (i.e., possessed a higher machinability), particularly brass, delta metal, cast iron, and the steels of greatest strength.

Conclusions

Tool steels. A study of the progress made in the art of cutting metals shows that in the majority of cutting trials made by differ-

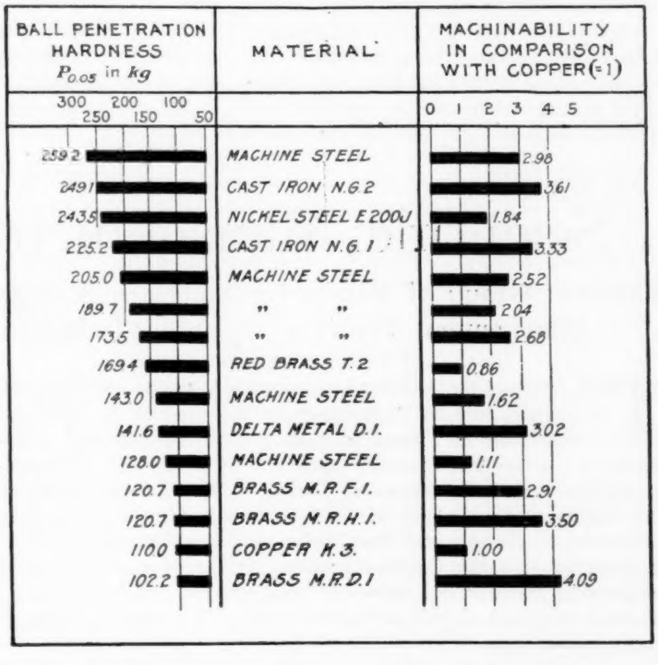


FIG. 17 BALL-PENETRATION HARDNESS (MARTENS-HEYN UNITS) AND MACHINABILITY OF VARIOUS METALS AND ALLOYS

ent experimenters a number of different grades of tool steel were used which were obtained from various leading manufacturers. This system is therefore one of elimination, for it is evident that one class of tool steel will have its special field of usefulness when applied to a material of given physical properties and chemical composition.

Smith and Hey in their trial chose one particular brand of steel (A.W. high speed) and their heat treatment of this was such that it was most efficient when taking extremely light cuts.

Chip Formation and Form of Tool. It is evident that the subject of chip formation continues to receive considerable attention. With respect to this important factor, it should be noted that the shape of the cutting tool used is quite different from those ordinarily used in previous experiments. To be sure, the Taylor, Berlin, and Manchester tests twenty or more years ago did establish a form of tool which at that time was far superior to anything previously developed, and that form today is accepted as standard, although in many manufacturing plants we find tools far different from the accepted standard contours but which are giving very satisfactory service and incidentally a different form of chip. It may be that the new form of cutting tool used by Smith and Hey in their experiments may account somewhat for the character of the chip, and also for the rather remarkable results obtained in the forced trials.

Red Hardness. The peculiar phenomenon that occurs in high-speed steel and is called "red-hardness" is in a fair way to be explained and classified. At least the results thus far obtained with the Herbert hardness-testing machine have succeeded in practically determining this quality. But even if we deny the validity of the results obtained, we must admit the truth of Mr. Herbert's

statement that "an adequate knowledge of the working properties of tools and of work materials can only be obtained by testing them hot."

Secondary Heat Treatment and Hardness. Fig. 2 should receive more than passing attention, particularly the fact disclosed by that graph that subsequent heating below 575 deg. cent. for the particular grade of steel (A.W. high speed) used does not appreciably affect the hardness of the steel. Now if the cutting of the tool can be maintained at a temperature below 575 deg. cent. the tool will maintain its original hardness but if a temperature of 575 deg. cent. could be held throughout the duration of a cut the tool would then be doing its most efficient work.

The durability trials that were rechecked offer almost conclusive evidence that at speeds where the red-hardness quality of a steel is of value, a secondary heat-treatment is required to prolong the life of the cutting edge.

Force on the Cutting Tool. Referring to Fig. 5, the values of the initial force on the cutting tool show that it is least at the slowest speed, indicating that the least resistance is offered by the material being cut, and also at this speed the tool is in its coolest state; its durability at these speeds, however, is extremely low.

This, then, is in support of a previous statement and should lead us to believe that a cutting tool is doing its most efficient work at a time when the resistance offered by a material is sufficient to raise the temperature of the tool to its maximum secondary-heat-treatment temperature.

The apparatus developed by Drs. Heyn and Kessner for machinability determination will not give absolute values and it is very doubtful if values of even a comparative nature may be obtained. While appreciating the efforts of these experimenters in attempting to reduce to numerical values the machinability factors, it must nevertheless be said that the application of their principle in practice, or more particularly, in detail, will fail to give true value because of:

a The hardness of the drill used is a most variable factor

b The durability of the cutting edge is a variable controlled by the hardness or the resistance offered by the material being cut

c The cutting angle of the drill cannot be the same for all materials as different cutting angles will give a longer or shorter life to the drill, and will also cause it to cut more efficiently on one material than on another.

Scientific Management at Prague Conference

Valuable Group of Papers by American Authors at International Management Congress Treat of Management Problems Including Industrial Relations, Bugetary Control and Education

THE program for the First International Management Congress at Prague, July 20–24, was largely the result of the efforts of a committee on American participation consisting of representatives of the American Management Association, the Management Division of The American Society of Mechanical Engineers, the National Association of Cost Accountants, the Society of Industrial Engineers and the Taylor Society. The papers were selected to give the Czechoslovakians information about recent progress in management science. They covered a wide field of industrial endeavor, as will be shown by the brief abstracts which are given below.

The Nature of Scientific Management

The first session of the Congress was opened by the presentation of a paper by Fred J. Miller, entitled, Scientific Management—Its Nature, Tendencies and Achievements, in which the author emphasized the importance of Taylor's concept of management as a true science resting upon principles that can be clearly defined and that are applicable to every kind of human endeavor from the simplest individual activity to the work of a great corporation requiring the most elaborate coöperation. He pointed out that Taylor's plan provided for the improvement of the management function and the training of workers, the most important elements in securing the highest possible efficiency. Workmen do far better when reinforced by management which provides them with the best available tools, with materials when wanted, and with the preceding operations properly carried out. Mr. Miller emphasized the contribution of Henry L. Gantt, who, from his experience gained with industry during the war, changed his procedure of installing management methods so that he enlisted in every case, and from the very first, the coöperation of both the foremen and the superintendents by giving them responsibilities in carrying out the work according to the new methods which were to be installed.

Supplementary discussions by Robert T. Kent, Prof. Joseph W. Roe, and Morris L. Cooke, dealt with individual phases of management. Mr. Kent pointed out that scientific management does not depend upon a set of forms but is rather a collection of definite principles whose application is varied to suit the needs of a specific case. Professor Roe reiterated the fundamental that good management consists in supplying the materials of production when, where, and in the condition needed. Mr. Cooke stressed the need which exists for mutual confidence between management and employees.

Management in Czechoslovakia

Doctor Verunac related the efforts being made in Czechoslovakia to develop better methods of management and to reduce waste. He told of the establishment of the Masaryk Academy of Work, the Institute of Engineering and Industrial Management, the Commission for the Study of Economical Methods, the Standardization Society, and the Institute for the Economical Use of Fuel. He also paid a tribute to the American Report on Waste in Industry, which, published in Czech by the Masaryk Academy of Work, was an effective means of securing broader understanding of the program of waste elimination that was so necessary in Czechoslovakia. Following the methods outlined in this book for studying waste elimination, commissions were appointed and at the time of the Congress three published reports were available, one on Protective Measures against Accidents, a second on Economies in the Miller's Trade, and the third, a printed cycle of lectures on management. Commissions have been established to study waste in the textile industry, in the glass industry, in the manufacture of footwear, in agriculture, and in transport.

Stan. Spacek made a strong appeal for increased coöperation among organizers and engineers in adjusting a world policy for peace. He paid a splendid tribute to the work of the American committee in bringing into his country new ideas and arousing new energy in the solution of the severe problems of reconstruction with which they were faced.

Dr. B. Tolman explained the functions of the Masaryk Academy of Work which are to further the systematic study and scientific organization of technical work paying attention to economic functioning, to support the scientific research, to encourage the training of scientific research workers to take part in the fundamental solution of the technical duties of the public administration by presenting schemes and criticisms; and to instruct the people in the objects of work.

The Individual in Industry

The second session of the Congress was devoted to the human element in management. The individual relations between the employer and the employee was discussed by Henry C. Link. In his paper Mr. Link covered the points of contact between the two, treating of safety engineering, medical service, health maintenance, industrial fatigue, proper selection of employees, labor turnover, psychological studies, job specifications, the training and education of employees, the training of foremen, general education and goodwill, organized personnel administration. Under the heading of

labor turnover, Mr. Link pointed out that one of the important results of study of labor turnover was the accumulation of records of the motives for employees changing their work. The reasons were classified as dislike for work, dislike for the working conditions, dissatisfaction with discipline, work too difficult, wages too low, and better job elsewhere. In conclusion, Mr. Link stated emphatically that the leaders of American industry have acquired a large vision of the importance of the individual as a factor in industrial progress.

In his paper on Labor Relationships in American Industry, Edward S. Cowdrick treated two phases—industrial relations practice and financial incentives. The first part outlined the principles of industrial justice and traced the development of labor unions and recent forms of employee representation. The second part of his paper outlined American methods of wage payment and discussed profit sharing and stock distribution. In his conclusion Mr. Cowdrick pointed out that no simple formula has been devised by which labor problems can be eliminated. Their solution calls for persistent effort, humane purpose and patience. American methods are not necessarily applicable to other nations. Justice and good-will, however, are universal.

Budgetary and Production Control

Two sessions were devoted to the control of industry from the standpoint of business as a whole and from the production viewpoint. This session created a great deal of interest and provoked considerable discussion. The Development of an Industrial Budgetary Control, by Howard Coonley proved to be an excellent contribution to the subject. Mr. Coonley traced the need for budgetary control and stated its objects to be: First, a sales guide to provide an accurate forecasting of customer demand as a basis for production and a foundation for a merchandizing campaign; second, a production guide to give an intelligent manufacturing program to prevent employment fluctuations and to provide maximum production in the season when efficiency is at its highest point and the labor supply ample; third, a financial guide to estimate the working capital permanently required by the business and to indicate the outside money needed to take care of peak investment. The three fundamental necessities for proper budgetary control are: A sound plan of organization with the authorities and responsibilities of the organization well defined and adequately maintained; records so established as to place definite responsibility on each unit of the organization; a business budget which is a forecast of future accounts in terms of organization responsibility.

Production Control was the title of the paper by George D. Babcock which pointed out the importance of careful preplanning to ensure efficiency of production and maintenance of manufacturing schedule. Mr. Babcock discussed the factors that must be considered in determining such a schedule, such as operation analysis, stores systems, dispatching of work, inspection and maintenance.

Education

Education for the Profession of Engineering was the title of the paper by Wm. E. Wikenden, in which he outlined the peculiarly American problems of engineering education. He traced the influence of pioneer life, the effects of the early American colleges, and the value of public secondary education in the general plan of higher education in America. He pointed out that the total investment in plant and endowment in 137 engineering colleges in America was about $150,000,000 and the total of their annual budgets between $20,000,000 and $25,000,000. The enrollment in 1923 in these institutions was 52,290, and in that year 9500 engineering degrees were conferred. In dealing with recent developments Mr. Wikenden mentioned the coöperative plan of instruction the increased attention that is being given to the study of human nature and conduct and the organized human relations in industry and government. A third significant development is found in the rapidly growing centers of post-graduate training and engineering research, and the fourth development is the coöperative project being carried out by the Society for the Promotion of Engineering Education for the collection of experience from the various schools, and a survey of the occupational demands confronting engineering schools, a study of the ways and means by which engineering schools may be effectively related to the organized life of the engineering profession and a study of the corresponding activities in Europe.

Value of Technical and Vocational Training

In the discussion Doctor Verunac emphasized the great value of technical training in countries that required economical reconstruction. He suggested the foundation of chairs of engineering and industrial management at the technical schools and colleges in the states of the Little Entente and that a special state examination be instituted at the higher technical schools and colleges in Czechoslovakia, which would deal primarily with technical management and economics.

Vocational Education was the subject of the paper by Channing R. Dooley. He outlined the steps of development of vocational training in the United States. He pointed out that the purpose of vocational education was to give to each student the kind of training which he or she requires to earn a livelihood with the maximum efficiency according to natural ability and ambition, and to give him or her the broader ideals of life which will make better citizens. He also stated that in all industrial education opportunities must be provided for movement from one branch to another in line with the student's developing abilities and with changing conditions. He also included in the principles of good business that a manufacturing concern should provide and maintain a training in fundamental subjects which will assist in developing skilled mechanics to carry on the business of the future.

Business Training

George W. Coleman discussed advanced and special education for commerce and business administration in universities, colleges, and engineering schools. After a thorough treatment of the aims and objects of business training and an outline of the growth, development and present practice of business training, Mr. Coleman stated that in the future the leadership in business would rest with those who had passed through a course of fundamental training in economics. He stated further that in America we must discover how to mobilize the assets and energies which are already in our possession and that we must learn the lesson of conservation.

Supplementary Papers

In addition to the papers forming the regular program, there were a large number of supplementary papers dealing with various subjects. Roy V. Wright reviewed the problems of American railway management, discussed employee representation, collective coöperation by labor unions, and in summing up stated that splendid progress is being made in bridging the gap between management and workers, not only to their mutual interest, but to that of the public which depends upon the railroads for service.

Sanford E. Thompson discussed management in the coal industry in which he presented valuable information on progress in coal mining methods and showed the importance of the use of machinery and good management in mine operation.

The following papers were also presented at the Congress: Sales Management, by C. K. Woodbridge; Industrial Research in the United States, by Maurice Holland; The Problem of Efficient National Administration, by W. F. Willoughby; United States Department of Commerce and Its Relation to Business, by H. Lawrence Groves; The Role of Machinery in American Agriculture, by H. R. Tolley.

Industrial Visits

Upon the close of the Congress the delegates were conducted on a week's trip through the industries of Czechoslovakia. Notable visits were made to the Skoda Works at Pilsen and the Witkowitz Steel Works, Ostrava. In the Skoda Works which were almost entirely rebuilt since the war, the particular feature of interest was the foundry where electric arc furnaces were used instead of cupolas for melting the iron. The forge shop was well equipped with hydraulic forging presses and large steam hammers. Their forge products include steamship frames, car wheels, gun forgings and other large work.

SURVEY OF ENGINEERING PROGRESS

A Review of Attainment in Mechanical Engineering and Related Fields

The World Power Conference

THE September issue of MECHANICAL ENGINEERING contained brief descriptions of a few of the 400-odd papers presented at the first World Power Conference, held in London June 30 to July 12. This month two important Conference papers by American engineers have been selected for consideration, and extended abstracts of them appear below.

Present Practice in Steam Generation in the United States

THIS paper deals mainly with the practice of the Babcock & Wilcox Company with which the author, Dr. D. S. Jacobus, is associated in the capacity of advisory engineer. The paper stresses the subject of high steam pressures because of the great interest in it at the present time, but deals also with stationary boilers and their superheaters, economizers, air heaters, and to a certain extent, marine boilers.

The author comes to the conclusion in reference to the question of best pressure and temperature at which to operate a steam power plant that in a base-load plant it pays to employ higher pressures and temperatures than in one having a low load factor. There are, however, a number of factors to be considered in determining the economy of a plant, some of which are discussed in detail.

The great majority of boilers built for higher pressures and temperatures have been for supplying steam at a gage pressure of 350 lb. per sq. in. or thereabouts, at the turbine throttle, where the steam is not resuperheated between the stages of the steam turbine. Boilers having a total heating surface of about 2,560,000 sq. ft. were sold prior to 1924 for 54 stations for working pressures of 350 lb. or more. Of these, boilers having 400,000 sq. ft. were for 650 lb. working pressure. In the latter plants the steam is resuperheated.

The limit of capacity of boilers ordinarily depends on the maximum amount of fuel that can be burned and the draft available for overcoming the resistance of the gases flowing through the boiler. Today boilers are regularly installed to evaporate from 8 to 10 lb. and more of water per hour per square foot of heating surface.

As regards efficiency, a distinction is made between the highest thermal efficiency and the highest commercial efficiency, both of which are discussed in some detail. Additional efficiency may be secured by causing the gases which flow through a boiler to pass over a greater number of rows of tubes, and, in some cases, by changing the arrangement of the tubes.

Increasing the number of passes of the gases over the tubes increases the draft loss, much of the loss being due to the change in direction of the gases in passing over the ends of the baffles. This has led to an endeavor to minimize the number of passes and the Babcock & Wilcox Company built a number of two-pass boilers. It may be asked, Why not use a single pass? The answer is that a single-pass boiler for a given capacity and efficiency would cost more than a two-pass boiler. The two-pass boilers also lend themselves more readily to separating the soot and cinder from the gases and fit in well with most plant layouts when used in connection with economizers and air heaters. A two-pass boiler costs more than a three-pass boiler for a given capacity and efficiency and most boilers are three-pass. In the case of Stirling boilers, the gases are made to pass three or four times lengthwise of the tubes, including the pass over the tubes next the furnace, and in some cases five times.

The use of economizers and air heaters is extensively discussed, in particular, a series of tests dealing with the elimination of free oxygen from feedwater and how this problem was finally solved. The greater part of the economizers now installed by the Babcock & Wilcox Company have tubes inclined slightly upward from the horizontal in the direction of flow of the water through them. Two-inch seamless steel tubes are used and the method of their attachment is described. The air heaters made by the company are of the tubular type, as they cost less than plate heaters and are easier to repair.

The gain in efficiency due to the use of air heaters may be greater than that corresponding to the heat absorbed by the air heaters, on account of the effect of the heated air in increasing the heat absorbed by the boiler and improving the efficiency of combustion. In certain cases air heaters have the added advantage of increasing the available boiler capacity 10 to 15 per cent by making it possible to burn a greater amount of coal. They are also advantageous where extraction feedwater heaters are used which heat the feedwater to a point that reduces the amount of heat available for absorption by economizers, in which case they are used either with or without economizers.

FURNACE DESIGN

Furnace design may be coördinated with that of the boiler to secure the best results. From time to time ways are suggested for measuring the efficiency of a boiler apart from that of the furnace, all of which have been approximate. The line of division between the stoker-and-furnace efficiency and the boiler efficiency is influenced by delayed or secondary combustion between the boiler tubes, which is an element that cannot be included in any analysis. The effect of excess air is another element which cannot be correctly divided between the boiler and furnace. The combined unit should therefore be considered in any study of efficiency or capacity.

Furnaces are made considerably larger than in former practice. For coal-fired boilers with forced-blast chain-grate stokers the latest installations have about 4 cu. ft. of furnace volume per 10 sq. ft. of boiler heating surface. In the case of the latest powdered-fuel furnaces the volume is about 6 cu. ft. per 10 sq. ft. of boiler heating surface. In the latest installations for blast-furnace gas, the furnaces have a volume of at least 2 cu. ft. per 10 sq. ft. of boiler heating surface. These figures are for the larger furnaces used in stationary practice. With smaller furnaces a considerably higher capacity is often developed than these rules would call for. As has already been stated, most coal- and oil-fired boilers used in power plants are called on to evaporate from 8 to 10 lb. of water per hour per square foot of heating surface as a maximum, and at peak loads 60 lb. of water or more may be evaporated per hour per cubic foot of furnace volume. In marine practice as high as 150 to 180 lb. of water may be evaporated per hour as a maximum per cubic foot of furnace volume in both coal- and oil-fired boilers. It is necessary to operate with the cleanest of feedwater and with the highest class of attendance in order to secure such high capacities.

The very high furnace temperatures used nowadays give importance to the question of maintenance of the brickwork. Where furnaces are operated under a suction the cooler air from the outside percolates inward through the brickwork and serves to prevent overheating, whereas, if operated under a pressure the hot gases percolate outward and increase the temperature of the brickwork. This may cause all the difference between the success or failure of a furnace. The load carried by the brickwork affects its likelihood of failure by plastic deformation.

Firebrick of the best quality ordinarily used in boiler settings, which have a fusing somewhat higher than 3100 deg. fahr., may show plastic deformation under a load of 20 lb. per sq. in. at 2000 to 2200 deg. fahr. A reduction of the load to 10 lb. per sq. in. will increase the temperature at which the bricks begin to deform about 200 deg. fahr. As furnace temperatures of from 2700 to 3000 deg. fahr. exist with certain grades of fuel, it is apparent that care must be taken to cool the brickwork.

The absorption of radiant heat by boiler tubes has a considerable effect on the maintenance of the furnace brickwork and affects the design of the furnace for various fuels. Furnace design from the point of view of cooling, including air cooling of the walls and wall cooling by placing boiler tubes in the walls, is discussed in the original paper. The author discusses the methods employed for overcoming trouble from slag adhering to boiler tubes or furnace walls, as well as trouble due to poor feedwater.

Boilers for High Pressures and High Temperatures

The first boiler of this type with which the Babcock & Wilcox Company experimented has become known as a "series" boiler. In this boiler the steam passed to a separating tank before entering the superheater and the water was maintained at a given height in the tank by regulating the supply of feedwater and at the same time allowing a small amount of water to be blown continuously from the tank and returned to the feedwater. Another type of series boiler experimented with was used in combination with a relatively small boiler for a steam-and-water drum.

The boilers now under construction for 1200 lb. working pressure use tubes 2 in. in diameter, which is a convenient size for internal cleaning, and employ a steam-and-water drum to provide a reserve water capacity, which is highly desirable in starting up a boiler and in operating a boiler under variable loads. The possibilities of operating without a steam and water drum were carefully considered. This would, of course, make it necessary to provide feed pumps having 100 per cent reliability. The relative merits and cost of the single steam-and-water drum for providing reserve water capacity as compared to a multiplicity of drums or tubes were also considered, and it was finally agreed that a boiler with 2-in. tubes and with a single steam-and-water drum was the best.

The author concludes his paper by describing some typical installations of stationary and marine boilers. Of particular interest is the projected installation of the boiler for 1200 lb. working pressure at the Weymouth Station of the Edison Illuminating Company of Boston.

The ends of the horizontal circulating tubes which run from the uptake headers to the steam and water drum are bent so as to make them enter the drum in circumferential lines which are twice as far apart as the distance between the headers. This greatly increases the efficiency of the ligaments between the tube holes.

The counterflow economizer is made up of 2-in. seamless steel tubes; it is built so as to be subjected to the full working pressure of the boiler plus the pressure required for passing the water through the feed valve which comes between the economizer and the boiler. The heating surface of the boiler is 15,732 sq. ft. and of the economizer 11,110 sq. ft., or 70.6 per cent of the boiler heating surface. It is proposed to evaporate 143,000 lb. of water per hour as a maximum, corresponding to 9.1 lb. per hr. per sq. ft. of boiler heating surface. A Carty cinder catcher is placed between the boiler and the economizer; this consists of a number of V-shaped gas passages between the elements. The separator elements have open ends and open bottoms and the cinders are thrown out through being projected downward from the narrow ends of the separator elements and through turning the gases under the sides of the separator elements into the upward flowing streams of gas which come between the elements.

Fig. 1 shows a side view of a Class W Stirling boiler with economizers installed at the Trenton Channel plant of the Detroit Edison Company, for firing with powdered fuel. Instead of connecting the water-screen tubes into the circulation of the main boiler they are made to form two separate small boilers. The boiler is built for a working pressure of 416 lb. per sq. in. and has a heating surface of 29,000 sq. ft. The combined heating surface of the two water screen boilers exposed to the direct heat of the furnace is 1190 sq. ft. There are two economizers, each having 9492 sq. ft. of heating surface, the total surface corresponding to 65.5 per cent of the boiler heating surface. The economizers are of the counterflow type, divided to provide for both an upward and downward flow of the gases over the tubes. It is proposed to evaporate about 300,000 lb. of water per hour as a maximum, which corresponds to an evaporation of 10.3 lb. per hr. per sq. ft. of heating surface.

The subject of efficiency secured in modern installations is discussed on the basis of curves representing results secured in a great number of tests of stationary boilers. From this it would appear in general that the efficiencies for powdered Eastern semi-bituminous coal shown by the curves in the original article are about 1 per cent higher than for the same coal fired on an underfeed stoker. The percentage of CO_2 in the flue gases for the underfeed stoker was taken at $12^1/_2$ per cent at the lowest load and $14^1/_2$ per cent at the most favorable loads. With the underfeed stoker the percentage of combustible in the ash was taken at 6 per cent at the lowest load and 11 per cent at the highest load.

The efficiency shown for powdered Western bituminous coal is about $5^1/_2$ per cent higher than for the same coal fired on a forced-blast chain-grate stoker. No deduction was made for the fuel

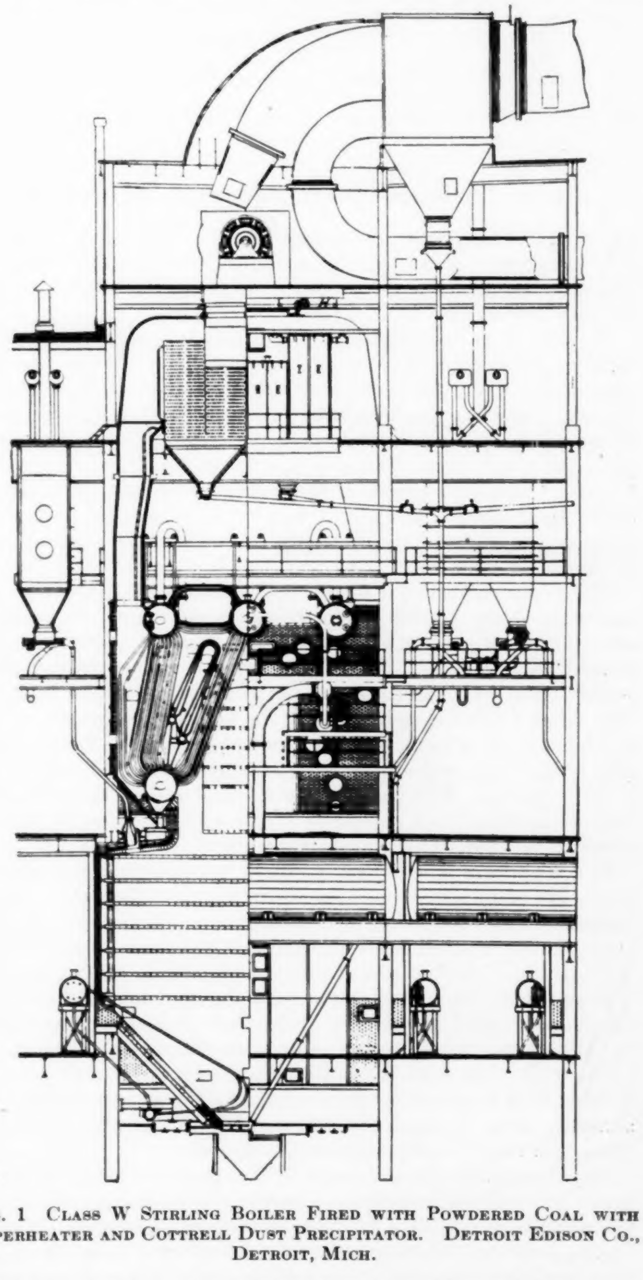


Fig. 1 Class W Stirling Boiler Fired with Powdered Coal with Superheater and Cottrell Dust Precipitator. Detroit Edison Co., Detroit, Mich.

required to dry the coal to a point where it would contain 4 per cent of moisture, which, if included, would reduce the difference in the efficiencies to about $3^1/_2$ per cent. The CO_2 in the flue gases for the forced-blast chain-grate stoker was taken at about 10 per cent at the lowest load and somewhat over 14 per cent at the highest load. The combustible in the ash was taken at 6 per cent at the lowest load and 20 per cent at the highest load. Table 1 illustrates in a few figures the great advance in development of boiler practice made in the last twenty years, an advance all the more significant in that notwithstanding the rise in the same period of the internal-combustion engine and the development of water power, the boiler still main-

tains its preëminent position as the most important element in power generation. (Dr. D. S. Jacobus, Advisory Engr., Babcock & Wilcox Co., New York City. Mem. A.S.M.E. Abstracted from mimeographed copy, *geA*)

TABLE 1 COMPARISON OF POWER-PLANT BOILERS OF 20 YEARS AGO WITH THOSE OF TODAY

	20 years ago	Today
Heating surface, average	2,500	12,000
Heating surface, largest single boiler	6,040	29,000
Heating surface, largest single unit[1]	6,040	30,590
Working pressure, lb. per sq. in.	225	350 to 650 and 1200
Total temperature of superheated steam, deg. fahr. max.	550	700 to 750
Maximum rate of evaporation, lb. per sq. ft. per hr.	5	8 to 15
Maximum rate of evaporation, lb. per hr. per boiler	30,000	300,000
Furnace volume in cu. ft. for each 10 sq. ft. of heating surface	0.5 to 1.0	2 to 8
Volume of boiler setting for largest boilers, cu. ft.	7,650	90,000
Height from bottom of walls of setting to center of steam and water drum for largest boilers, ft.	19	55
Boiler surface installed per maximum kw. capacity, sq. ft.	7	1.5

[1] By a single unit is meant two boilers set over the same furnace.

Steam Turbines and Condensing Equipment

A GENERAL paper, by Francis Hodgkinson, dealing with developments principally in America. Only certain parts of this extensive and interesting paper can be abstracted here because of space limitations.

For large sizes the builders have recently turned to compounded turbines, either tandem or cross-compounded, and at least from the viewpoint of today, for turbines of 50,000 kw. maximum continuous capacity and greater and for turbines of almost any large sizes where steam pressures higher than 400 lb. are employed the compound principle in one form or another will be adhered to. The General Electric Company, however, has produced eminently successful machines of 50,000 kw. capacity at 1200 r.p.m. as single complete-expansion machines for the Detroit Edison Co. and lately for the Brooklyn Edison Co.

The paper comprises a highly interesting tabulation giving the last-blade characteristics of representative machines. One column gives the actual annulus of the last row of blades. Another column, termed "quality index," gives a figure which combines the features of conservative design and low stresses with large low-pressure areas. This figure (which is merely one of the sequence of quality on the sole basis that low stress and low terminal loss are the things sought after) with its terms to some fractional exponents may be regarded as a quality factor. Still another column gives the K constant for the various machines and represents the sum of a number of turbine elements reduced to a common blade speed.

In comparisons of low-pressure blades designed for equal velocity ratios, low blade speeds have the advantage of smaller velocity components parallel to the axis of the turbine, and hence lower leaving losses, and two-speed cross-compound turbines lend themselves to this feature. The last row of blades will pass the same maximum volume per square foot of annulus for any blade speed, the leaving losses being equal, provided a blade angle is selected appropriate to the particular blade speed. Curves in the original article show, for example, that with 440 ft. per sec. blade speed and 75 per cent opening, 0.83 lb. per sec. at 29 in. vacuum will flow per square foot of annulus. Any variation of blade speed from this will require less steam flow to secure the same low leaving loss.

Impulse-turbine elements used to be regarded as highly advantageous in lending themselves to fractional admission of steam, i.e., the nozzles occupying a fraction of the circumference. This involves, however, two serious sources of losses and today in all impulse-turbine design nozzles are made to occupy as much as possible of the whole circumference. The author explains by a formula why individual or group control of nozzles does not produce the gain in efficiency sometimes expected.

In any turbine blading, the larger the blade passage, the greater the efficiency because of the lesser ratio of perimeter to area, and hence, less friction loss. Because of higher steam velocities and greater energy conversion in impulse elements, any departures from the ideal blade form are more marked in results as compared with reaction elements.

The opinion is generally held that nozzle efficiency falls off more rapidly after passing the critical velocity. Some experimenters have maintained that maximum efficiency occurs at that velocity and there is a good deal of conflicting data on the subject, much of which is based on experiments with nozzles discharging against a target.

In an actual turbine, however, blade losses may be totally different from experimental data of this kind because of the effect of the moving edges, displacement, entrainment, etc. Many factors may obscure results. For instance, small turbines with wide blades, having small arcs of admission, might show superior results from such experimental tests, while in practice they would be less efficient because of high displacement loss.

It would seem evident that the highest blade efficiency is secured with lowest velocity, and that impulse blade efficiency is affected by the ratio T/R, which is the ratio of the steam stream thickness to the radius of curvature of the concave surface of the blade.

Loss due to friction on the blade, compression of the steam due to reversal of direction, stream interference and "straight blow-through," all increase with high value of T/R. Consequently, it is evident that as the edge thickness loss decreases with increase of T/R, a point of minimum loss occurs at some relatively low value of T/R for each steam velocity and blade width. In practice, curves have been determined by the analysis of results from actual impulse wheels. The edge loss remains constant for any value of T/R. The velocity losses increase with the higher velocities; hence T/R should have lower values with higher steam velocities as shown by the curve. By increasing the width of blades, further reduction of loss may be secured with lower values of T/R because of the reduced edge loss, and with fewer edges passing in front of the nozzle, less disturbance of the stream lines occurs.

The values of T/R employed in Westinghouse turbine practice for two-row impulse elements vary from 0.3 in the first moving row to 0.6 in the second moving row for steam nozzle velocities of approximately 2000 ft. per sec.

Practical designing and the employing of desirably low values of T/R lead to wide blades and have resulted in Westinghouse impulse blades being wider than those of other manufacturers.

The results obtained with blading designed with the above points in view seem to justify the above conclusions. A notable point is that with this form of blade, an erosive cupping action so often seen within the blade passages of narrow impulse blades has not been observed, even with many years' operation with wet steam and steam velocities exceeding 3000 ft. per sec. It is obvious that a given degree of erosion is far less detrimental to the efficiency of a wide blade than a narrow one.

Some of the features of design of large modern Westinghouse turbines (35,000-kw. 1800 r.p.m.) involve employment of multiple exhaust blading, the blades being of warped surface and of tapering section so that the maximum stresses in the blade due to centrifugal force do not exceed 20,000 lb. and the average stress on the drum is 18,000 lb. (both calculated on the bases of 20 per cent overspeed).

The nozzles are in three groups, the first group giving the capacity for the best point of steam consumption. This group occupies nearly half the circumference. The nozzles are formed from forged steel by a simple operation in a gear cutter, which also provides grooves into which are fitted stamped-steel partitions. The whole is welded together by a means similar to the Hyde process.

In order to make the turbine adaptable to extreme conditions of bleeding for regenerative feed heating, four bleeder outlets are provided at approximately $3^1/_2$ lb. abs., 16 lb. abs., 50 lb. abs., and 120 lb. abs. at the point of maximum efficiency.

It would be a gain if the lower stages of the turbine where the steam is wet could have the moisture abstracted as precipitated. An attempt is made for the first time to accomplish this in part in this design. Erosion of turbine blading shows plainly that the moisture in a turbine occupies the outer zone of the steam path, so these latter machines are arranged with the adjacent edges of the blade rings brought close together so that the velocity of the steam going to the heater at full load approximates 150 ft. per sec., and it is believed some proportion of the moisture will be carried away when the turbine is operating with full flow to the feed heaters. The effectiveness of this will be definitely determined in the near future.

Later designs of turbines now under construction are described. One for the United Light and Power Company, of 50,000 kw. capacity with the best point of steam consumption at 40,000 kw., is of the cross-compound type.

Another installation of a 50,000-kw. turbine is of particular interest, as it is for the base-load station being built for the Commonwealth Edison Co., at Crawford Ave., where the operating conditions will be 550 lb. steam pressure, superheated to 725 deg. total temperature, the steam expanding through high-pressure-turbine elements, then being reheated to 700 deg. and returned to lower-pressure turbine elements. This station will be doubly interesting because, to begin with, it will comprise three turbine units each built by a different company. All will bec ross-compound turbine. One, a 60,000-kw., is being built by the General Electric Co., in which a separate high-pressure, 1800 r.p.m. generating element will, at full load, expand the steam to 120 lb. abs. pressure, at which it will be reheated and returned to a single low-pressure, 1200 r.p.m. turbine expanding to the condenser pressure.

Another, a 50,000-kw., being built by the Westinghouse Co., is of the general arrangement shown in Fig. 2. The high-pressure and intermediate are arranged as a tandem compound, 1800 r.p.m. machine. At high load the high pressure expands to 132 lb. abs., at which pressure it is reheated and returned to the intermediate turbine element where, at full load, it is expanded to $16^{1}/_{2}$ lb. abs., passing to the low-pressure element driving its separate generator. Expectations of turbine performance of these machines have been based on a 10-lb. pressure drop through the reheater and its piping. It is important every precaution be taken to keep this at a minimum. Should this be as high as 25 lb. practically all gain in economy from reheating would be lost.

High- and intermediate-pressure turbines are arranged with steam flow opposite to each other, as shown in a figure in the original paper, so the one may neutralize the thrust of the other, eliminating the necessity of large drums or balance pistons. All condensers are vertical. The flanges connecting the condensers to the turbines are inclined to permit easy removal of the turbine-cylinder cover. The joints in the upper portion are without bolts and gaskets, tightness being maintained by circular-section rubber clamped over the joints.

A penalty for reheating is a complexity of regulating apparatus because the steam in the reheater and its piping would be sufficient to cause overspeeding in the event of the turbine being relieved of load. In the case of the Crawford Ave. installation, each of the three manufacturers has adopted a different method of handling this matter. That adopted by the Westinghouse Co. is shown in Fig. 3. The inner range of the speed-responsive device operates the single valve controlling steam to the turbine, and as the governor weights move out this valve is closed. Further outward motion of the governor weights simultaneously opens a bypass valve, bypassing steam from the reheating system direct to the condenser, and closes a butterfly valve in the inlet to the intermediate. A butterfly form of valve was selected in order to introduce the least interruption to flow, and is carefully designed of streamline form.

Some complexity is involved because the motions of the two sets of valves are reverse in direction. That is, the steam-admission valve having reached its seat, the governor must have continued range of operation in order to open the reheater bypass valve. Considering motion in the reverse direction, the governor weights swinging inward must have continued motion after the reheater bypass valve has reached its seat. This will explain the purpose of the collapsible and extensible links in connection with the relays of the two valve gears. These links have the powerful springs shown in the figure, which, if required to be extended and compressed by the governor, would interfere with its speed characteristic. Hence, the intervention of an additional relay between the governor and the relays of the valve mechanisms. These additional relays will require a greater rate of oil supply than the bearings if the valve gear is to respond quickly to speed changes, so an accumulator is installed, as shown in the diagram, which serves the double purpose of regulating the oil pressure in the governor system and supplying enough oil for one instantaneous complete swing of the valve gear without allowance for the quantity delivered by the oil pump. A feature of the system is that the charging or discharging of the accumulator does not affect the oil supply to the bearings, they continually receive the quantity delivered by the main pumps.

The additional relay in the governor mechanism and the collapsible and compressible links could have been avoided if relays had been employed having idle stroke corresponding to the whole travel of the governor. This would have increased their length excessively, so the plan adopted was preferred.

A further innovation of design is made because of the objection of carrying minor piping with 600 lb. pressures about the turbine. Oil relays are therefore employed in connection with the automatic stop, automatic throttle, etc. This objection also applies to the auxiliary oil pump, which, for obvious reasons of availability must be steam driven, and no lower-pressure steam than 600 lb., is available in the neighborhood. Hence the automatic control of the two auxiliary oil pumps is oil-relay operated in the manner shown.

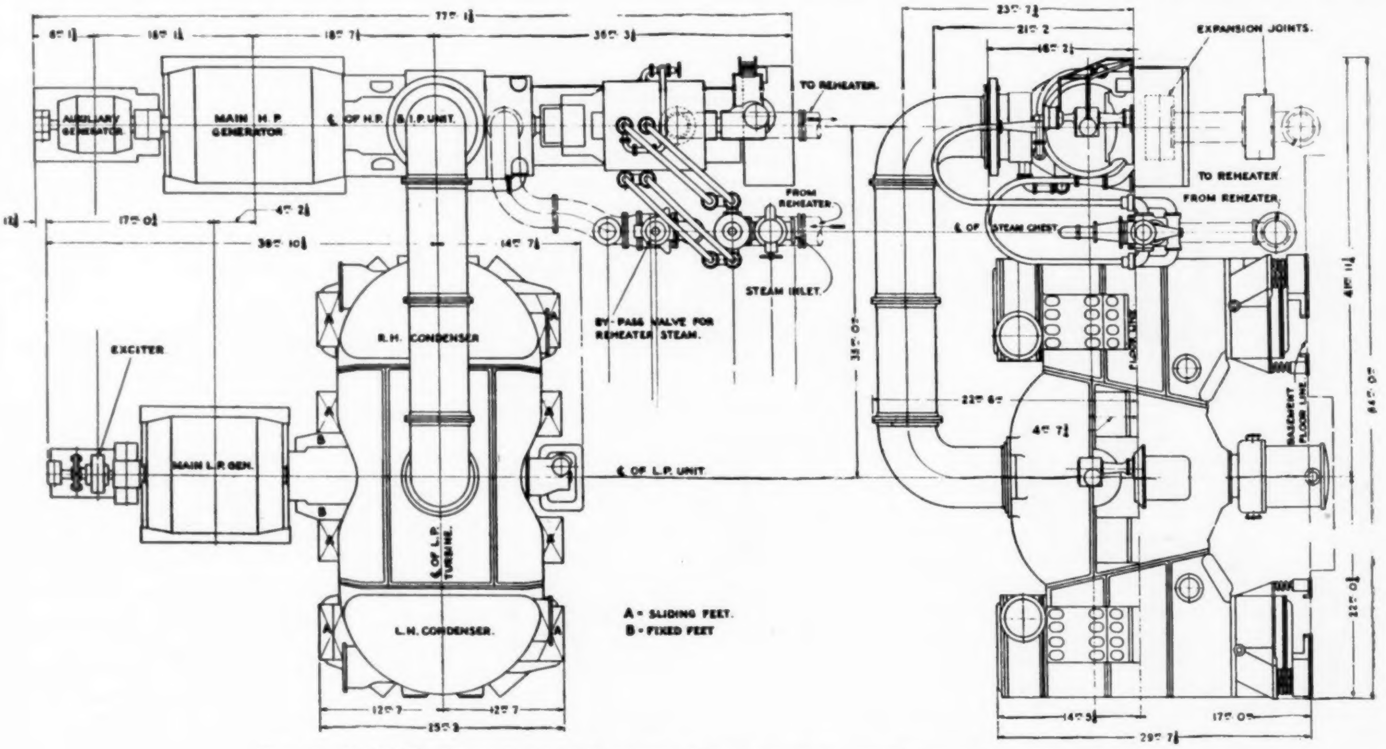


FIG. 2 50,000-KW. UNIT TANDEM COMPOUND BEING BUILT BY THE WESTINGHOUSE COMPANY

The arrangement of all these mechanisms is made clear in the diagram, Fig. 3.

The subjects of blade fastening and blade materials are extensively discussed, and complete analysis together with physical properties are given in the original paper. As regards materials, it would appear that either copper-zinc or copper-tin alloys, the latter containing phosphorus, are no longer employed for turbine blading. Nickel steel is employed by the General Electric and Westinghouse companies for impulse blading and by the Westinghouse Company for higher-stressed reaction blading. Cupro-nickel is employed considerably by the Allis-Chalmers Company and in some instances by the Westinghouse Company for turbine blading; manganese-copper is employed by the Westinghouse Company for low-stressed reaction blading while monel metal has been used to some extent by all companies, but the Westinghouse Company does not regard it, at least in its present commercial development, as a desirable material, because of non-uniformity and frequently the presence of carbon streaks and other imperfections which produce a greatly weakened and unreliable material. Stainless steels are not regarded favorably by the Westinghouse Company, because they do not lend themselves well to drop forging operations. Blades of this material should be machined all over. A low-carbon form of this material, beginning to be manufactured in the United States by the Firth-Sterling Steel Co., the Crucible Steel Co., of America, and the Allegheny Steel Co., is quite readily forged and believed to be as non-corrosive under normal blading service conditions as any other material although polishing is probably necessary to completely secure this non-corrodibility. The Westinghouse specifications for this material are as follows:

Chemical Composition

Carbon	0.07 —0.12 per cent
Manganese	0.80 per cent maximum
Phosphorus	0.03 per cent maximum
Sulphur	0.03 per cent maximum
Silicon	0.25 per cent maximum
Chromium	11.50 —13.00 per cent
Nickel	0.60 per cent maximum

The heat treatment after forging consists of quenching in oil from 1750 deg. fahr., drawing at 1200 deg. fahr., and cooling in oil. In this heat-treated condition the minimum characteristics are as follows:

Proportional elastic limit	60,000 lb.
Ultimate tensile strength	90,000 lb.
Elongation	20 per cent
Reduction of area	60 per cent in 2 in.
Izod impact	50 ft-lb.

The present objection to its use is cost.

The Allis-Chalmers Company use for their higher-stress reaction blading a material containing from 19 to 25 per cent nickel and from 6 to 9 per cent chromium with an ultimate tensile strength of 130,000 lb. This material is quite non-corrosive but is difficult to work, especially in machining, and its cost is high.

The subject of labyrinth packing as developed in the United States as a consequence of the employment of the Kingsbury thrust bearing (known as the Michell bearing in Great Britain) are discussed in some detail, and an instance is cited where the new bearing gave increased reliability and less leakage than an older type which it displaced.

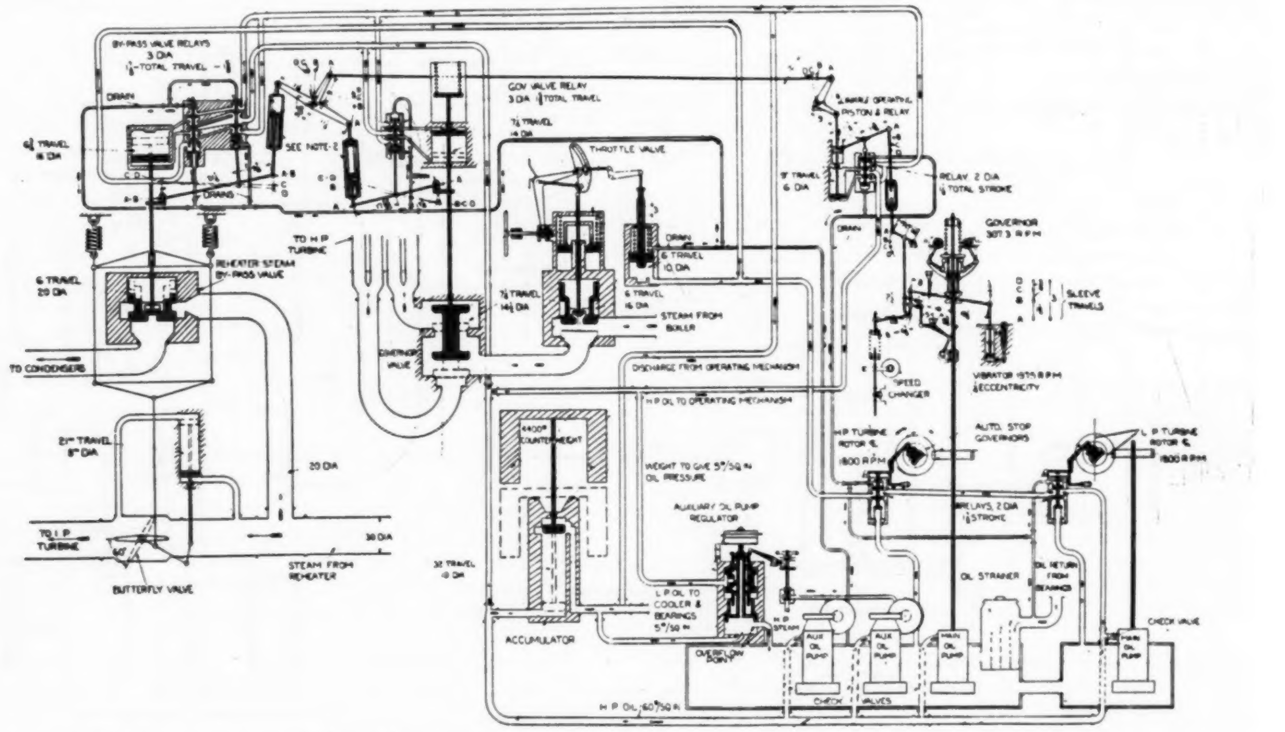


Fig. 3 50,000-Kw. Turbine, Commonwealth Edison Co., Crawford Ave., Showing Governor Linkage and Valve-Gear System of the Westinghouse Company

Higher Steam Pressures

Both the General Electric Company and the Westinghouse Company are building experimental machines for 1200 lb. entrance pressure to exhaust against 300 lb. back pressure. One being designed by the Westinghouse Company of 3200 kw. capacity, will be of impulse-reaction type, to operate at 3600 r.p.m. A feature of the design is that the cylinder, which is quite small, will be made of rectangular blocks of steel bored out for the rotor and blading. A particular feature of the design is the mounting of the small turbine cylinder in such manner that it or the alignment will not be disturbed by the expansion effects of the exhaust pipe, which is also a main steam line serving the lower pressure units in the power house.

It is not believed the designing of turbines for pressures up to 1500 lb. will present any insurmountable difficulties, although no practical experience has been had of the erosive action of steam at such pressures. Low steam velocities will, however, be employed generally. It is believed that total temperatures of 750 deg. fahr. will not be exceeded.

Concerning turbine efficiencies with high-pressure steam, the curves of Fig. 4 have been prepared. Curve *A* shows the approximate stage efficiencies to be expected of the turbine elements of a turbine of modern design with 1200 lb. per sq. in. initial steam pressure exhausting against 29 in. vacuum. Curve *B* shows the average efficiencies of turbines of modern design from the pressures in the

abscissas to 29 in. vacuum. Curve C shows the effect of reheating to the initial temperature of one-third of the heat drop.

The remainder of the paper is devoted to the condenser plant.

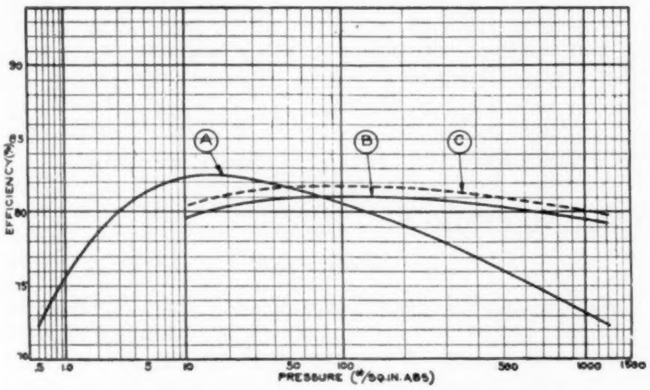


Fig. 4 Expected Turbine Efficiency Ratios at Various Pressures (Generator Losses *not* Included)

A—Approximate individual stage efficiency curve for a turbine expanding from 1200 deg. to 29 in. vacuum—no reheating
B—Average efficiency from pressures of the abscissas to 29 in. vacuum—no reheating
C—Same as "B" except reheating at approximately 1/3 the B.t.u. drop to 700 deg. total temperature, all curves based on 700 deg. initial total temperature.

(Francis Hodgkinson, Chief Engr., Westinghouse Elec. & Mfg. Co., Pittsburgh, Mem. A.S.M.E. Abstracted from mimeographed copy 35 figs., *dA*)

Short Abstracts of the Month

AERONAUTICS (See Internal-Combustion Engineering)

Oehmichen Helicopter

Description of the helicopter which was accepted by the French Air Service after having completed a circular kilometer, the first machine of its kind to achieve this feat.

The helicopter consists of four principal propellers and a system of five stabilizers, which are propellers of variable and reversible pitch. There are also two propulsion propellers with fixed pitch.

The apparatus weighs approximately 1000 kg. (2200 lb.) in working order, with the loading approximately 33 kg. per sq. m. (7 lb. per sq. ft.). The apparatus is said to be maneuverable and turns are easily accomplished. (*Aviation*, vol. 17, no. 7, Aug. 18, 1924, pp. 888-889, 1 fig., *d*)

Light-Airplane Flying Clubs

The Air Ministry announces that the Air Council has been greatly impressed with the aeronautical possibilities opened up by the development of the light airplane, in which England leads the way, and in addition to offering prizes for a competition, open to two-seater light airplanes, to be held at Lympne next month they are anxious that full advantage should be secured to the country from the progress which is being made with this type of aircraft.

The Air Council has reached the conclusion that these advantages can best be secured by encouraging, with the help of county and municipal authorities, the formation of light-airplane clubs throughout the country, and they are now prepared to assist financially, for a period of two years, the establishment of ten such clubs whose constitution is approved.

In the first instance it is proposed to endeavor to secure the formation of such clubs in the leading commercial centers of the country, and an Air Ministry representative will shortly visit likely centers with a view to discussing the details of the scheme which has been prepared with the local authorities and hearing their views on the subject.

Under the scheme the Air Ministry proposed to make to each club an initial grant, suitably secured, for the provision of approved types of light airplanes selected by the club, and an annual grant for two years toward the expenses of maintenance and the purchase of material and spares.

The club will be required to put up financial or other contributions to, at least, an equivalent amount, and to insure against loss or damage to equipment provided out of funds supplied by the Air Ministry. It will be required to make its own financial arrangements for suitable airdrome facilities and the necessary shed accommodation, and to employ one or more qualified air pilot instructors and ground engineers. It will also be responsible for the management of the undertaking and for the maintenance of the aircraft, but periodic inspection will be undertaken by the Air Ministry.

The Air Ministry will also make a grant to each club in respect of each member who qualifies for the issue of a private pilot's license on club aircraft.

The possibility of putting this scheme into operation at some date next year depends on the measure of success attained by the aircraft entered for the Government competition for two-seater light airplanes, referred to above. (*Flight*, vol. 16, no. 33/816, Aug. 14, 1924, p. 513, *g*)

AIR ENGINEERING

A Study of the Oxygen-Oil Explosion Hazard

There have been a number of oxygen-oil explosions and a still greater number of compressed-air explosions that may be attributed to oil.

A peculiar characteristic of oxygen explosions is the astonishing amount of mechanical power developed (that is, rate of liberation of energy) in relation to the small amount of combustible matter probably present. The violence of the detonation and general destructive effect seem out of proportion to the actual cause. If the containing vessel is made of steel it may burn like celluloid, or be splintered into brittle fragments like glass.

In the present investigation oil samples at first refused to explode, although the pressures were carried well beyond 2500 lb. per sq. in. When, however, the temperature was raised to about 120 deg. cent. (248 deg. fahr.) the first explosion occurred with linseed oil, which would indicate that not only pressure but temperature have to do with the explosion hazard. Moreover there are plenty of chances for this temperature to be exceeded under actual operating conditions, because it is the temperature of the oil volume that matters and oil is such a poor conductor of heat that the side of the film which is in contact with the oxygen might come up to its ignition temperature while the other surface is used in contact with the cool metal. There are two principal ways in which oil, if present, can quickly be brought to the danger temperature: (1) by slow leakage of high-pressure gas carrying liquid lubricant with it through some very minute opening—that is, by internal friction, which always generates heat; and (2) by sudden compression of the layer of oxygen nearest to the end of a closed passage, whether due to the impact of high-velocity oxygen rushing in from a quickly opened valve, or to direct connection with the compressor, as in the case of the Harvard explosion.

To register the final explosive pressure developed a special gage was designed, known as the multiple-disk pressure gage. This little instrument showed that an initial charging pressure of the amount usually carried in commercial cylinders, 1800 to 2000 lb. per sq. in., may lead to an explosion pressure of 20,000 lb. per sq. in. when a few drops of mineral lubricating oil are sufficiently warmed up to explode spontaneously in a Bureau of Mines standard steel bomb of 4 cu. cm. volume.

It has been found that the spotaneouns ignition temperature of oil is a constant that is independent of the oxygen pressure from atmospheric up to 3600 lb. per sq. in., the ignition temperatures varying from 120 deg. cent. for linseed oil to 175 deg. for kerosene oil; moreover, the ignition temperature for a given oil may be different for different-sized containers or other conditions. Among other things were investigated ignition of metals in oxygen and flow of gases, as well as the program developed for further research in the same connection. Practical safety precautions are also recommended. (Mayo D. Hersey, Mem. A.S.M.E., Physicist in Charge of Physical Laboratory, U. S. Bureau of Mines, Pittsburgh, Pa., in *Journal of The American Society of Naval Engineers*, vol. 36, no. 2, May, 1924, pp. 231–243, 3 figs., *ep*)

CORROSION

Protecting Rails from Corrosion by Oil Spraying

On the Delaware, Lackawanna & Western Railroad prior to 1910 average life of the road bed, including rails, bolts, ties, tie plates, and spikes, was only from eight to ten years. In 1910 the use of creosoted ties was adopted. This augmented the average life of the ties to 16 years. On the other hand, the experience of the railroad from 1910 to 1914 clearly indicated that it would be a serious mistake to increase the weight of the rails in order to make their life comparable to the longer life of the treated ties. The question was to find a way of preventing corrosion of the metal parts that would be effective and not cost too much. Because of the latter consideration painting rails and parts, galvanizing, or coating with aluminum had to be excluded. As a result of the numerous tests it was determined that a mixture containing 45 per cent asphaltum and 55 per cent crude oil when applied hot once a year would meet the practical requirements. As the mixture could not be put on by hand, a sprayer was developed by A. J. Neafie, principal assistant engineer.

This sprayer comprises a flat car carrying the apparatus, which includes a steam-driven air compressor. The sprayer car is pushed ahead of a train of tank cars containing asphalt oil. Each tank car is provided with heaters drawing on the locomotive for steam to heat the oil. Air at a pressure of 30 lb. per sq. in. is piped to the dome of the tank cars, and in this way the oil is forced through strainers to the spray nozzles located at the head of the spray car. There are four of these nozzles, one on each side of the rail. The sprays are so adjusted that the rails—except the heads and on track fixtures—are oiled to a point $^1/_2$ in. outside the tie plates. The sprayer travels at the rate of from 20 to 25 m.p.h., and in the fall of 1915 the total cost was only $4 per mile. Besides protecting the metal parts the oil lubricated the ties adjacent to the tie plates, which had a beneficent influence on the life of the ties.

A completely housed-in air-operated car is now used. The spraying apparatus is so arranged that its speed can be adjusted instantly to handle 100 gal. per mile or to give a lighter or heavier application of oil.

Prior to the use of oil, fully 50 per cent of the track bolts that were removed when taking up old rails had to be destroyed because corrosion had caused the nuts to stick so fast to the bolts that it was necessary to break them off. Bolts could not be kept tight without frequent renewal. With this form of protection, however, fully 95 per cent of the bolts can be tightened or reclaimed. This item alone justifies the expense of spraying. (*Compressed Air Magazine*, vol. 29, no. 8, August, 1924, pp. 963–964, 3 figs., *d*)

ELECTRICAL APPARATUS

Heavy-Starting-Torque Electric Motor

It has been estimated that 95 per cent of constant-speed electric-motor drives use motors of greater horsepower rating than necessary, because of the fact that the motor has to provide not only the regular power required to drive the machine but also the heavy torque to start it going.

From this point of view the motor recently developed by the Triumph Electric Co., Cincinnati, Ohio, is of interest in that while it is a squirrel-cage motor it develops a starting torque equal to about 275 per cent of the running-load capacity as compared with an approximate 80 per cent torque for the usual squirrel-cage motor.

This motor has two windings on one rotor, one a high-resistance winding for developing the starting torque, and the other a low-resistance winding for developing the normal running power. The idea of two windings on one rotor is not new, but considerable difficulty has been experienced in devising a short-circuiting mechanism that would be simple and reasonably free of trouble. In this case the current goes first into a phase winding which is an incomplete circuit terminating in three unconnected points in an automatic switch. Facing these points but held away from them by a spring coiled around the rotor shaft is a copper ring mounted on a plate. This plate acts as a centifugal governor, for from it are swung three weights. In proportion to the acceleration of the rotor the weights swing outward from the shaft until they force the plate against the spring, thereby bringing the ring into contact with the three points to complete the circuit of the phase winding. This happens when the motor reaches about 70 per cent of synchronous speed. It is stated that one of the largest billet shears in the country equipped with a flywheel is operated by a 40-hp. motor of this type, although normally it would require a 75-hp. motor. (*Iron Trade Review*, vol. 75, no. 8, Aug. 21, 1924, p. 490, 1 fig., *d*)

ENGINEERING MATERIALS (See Corrosion)

FUEL AND FIRING

Colloidal Fuel

This name has been given to mixtures of fuel oil with finely divided coal or other solid combustible. The advantages of such a fuel are fairly obvious. The outstanding difficulty with such mixtures has been to render them stable or permanent and to prevent the separation by subsidence of the particles of the solid fuel, always of higher specific gravity than the associated liquor.

One of the earliest attempts to produce a colloidal fuel was made by Plauson of St. Petersburg in 1913. His plan was to reduce the size of the particles of coal to actual colloidal dimensions by grinding the coal in the first place until it would pass a sieve with 200 mesh to the inch; then mix this fine powder with water or a liquid hydrocarbon and grind it further between polished plates running at a high speed and under a pressure of 60 to 100 atmos. The substance so produced presents all the properties of colloidal solutions or emulsions. The process may be accelerated by adding from 1 to 3 per cent of a "protective colloid," such as soap, milk, gelatine, or albumen, to the water, or soap solution, india rubber, etc., to the liquid hydrocarbon. The disintegration need not always be carried as far as the true colloidal condition. The production of an emulsion may often be sufficient.

Plauson's process did not attract much attention; furthermore, the cost and difficulty of the extremely fine grinding which he contemplated would seem prohibitive for the production of a fuel for industrial use. The more recent researches were carried on by the Engineering Committee of the Submarine Defense Association, formed in America in 1917 at the request of the British Admiralty and with the assistance of the Kodak Research Laboratory.

In the first experiments a semi-anthracite coal of specific gravity 1.467, pulverized so as to pass a sieve of 40 and to be retained on one of 80 meshes to the centimeter (80 meshes to the cm. is 200 to the inch) was mixed with an oil of specific gravity 0.900 and absolute viscosity 6, so that the coal formed about 30 per cent of the whole by weight. The settlement of the coal out of the oil was much smaller than was expected by Stokes' formula, but it occurred; and experiments with less viscous oils showed that with them it was more serious. Further, as the fuel before atomization in the burner required preheating and as the viscosity of all mineral oils falls off very rapidly with rise of temperature, it was necessary to provide a fuel which should not only remain stable at ordinary temperatures for long periods of storage but should also remain stable at higher temperatures during the comparatively short period of its flow through the firing system to the nozzle of the burner. The chief method by which this was accomplished was by adding to the mixed fuel a "fixateur," which acted like a protective colloid.

The fixateur or stabilizer which was found of most general use was a lime-rosin soap or grease. This was made by suspending five parts of slaked lime in 83.5 parts of Texas navy oil, adding 1.5 parts of water and ten parts of rosin, and heating until the rosin was saponified. The amount of fixateur needed depends upon the nature of the oil and of the coal; but usually the amount is such that the final product contains from 0.5 to 1.5 per cent of rosin. The rosin may be substituted by balsams, turpentines, or other resinous by-products, or by pinewood pitch; and other alkalis may replace the lime.

The first fuels made consisted of about 30 per cent of coal and 70 per cent of oil. The coal was pulverized, as though to be used as such: about 95 per cent passing through a sieve of 40 meshes to the centimeter (100 to the inch) and 85 per cent through one of 80 to the centimeter (200 to the inch). The oil and the requisite amount

of fixateur were measured out, and mixed with the coal in a ball tube, or paint mill. These fuels showed no sensible subsidence over a period of three months.

Another method of producing stability is the use of a "peptizing liquid"—that is, one which has the opposite tendency to an electrolyte, and instead of favoring the flocculation of the particles of the disperse phase into larger aggregates, tends to disperse them still further, reducing them to smaller particles in greater number. Such "peptizers" are found in many coal-tar products, such as creosote oil, naphthalene, solvent naphtha, or green anthracene oil. These may be used, in quantity amounting to from 5 to 20 per cent of the total fuel, either at the ordinary temperature or at a temperature of 65 deg. cent. (149 to 203 deg. fahr.), at which temperature the effect is usually greater, as is indicated by an increase in the viscosity, and by the greater number of particles in the mixture which are small enough to show the "Brownian movement" when examined under the microscope.

A third method, but one having several disadvantages, is to oppose the sinking of the disperse phase of coal particles by introducing similar particles of a "filler" of lower specific gravity than the oil, such as the waste from starch or flour mills, wood dust, finely divided peat or lignite. These particles will tend to rise slowly through the oil, and will interfere with and more or less nearly neutralize the downward tendency of the coal particles.

Any kind of pulverizable carbonaceous material may be used in making colloidal fuel.

Later experience has shown that it is preferable to grind the coal in oil, and that it is preferable to grind the materials hot rather than cold. The details of plans for manufacturing of colloidal fuels, including the use of flotation, are given in the original article.

Colloidal fuel can be utilized for marine steaming purposes under practically the same conditions and with as good results as with the navy oil. The saving of oil for equal weights of fuel was 31.2 per cent, but because of the lower heating value per pound of colloidal fuel compared to oil, about 10 per cent more of it, by weight, is needed to produce equal heating value. This means a saving, for equal heating value, of 27 per cent of oil. For equal heat units the colloidal fuel has nearly 2 per cent less volume than the oil with which it is made.

As compared with oil fuel, colloidal fuel is more concentrated, or contains more heat units in the same bulk, than oil, so that either space for fuel storage can be lessened by substituting colloidal fuel for oil, or the steaming radius can be correspondingly increased.

As regards the cost of manufacture, no figures from actual work seem to be available, but it is claimed that while the cost per million B.t.u. for oil is 47.1 cents, the same for colloidal is 41.8 cents. (Part 2 of *Pulverized and Colloidal Fuel*, by J. T. Dunn, Consulting Chemist, Newcastle-upon-Tyne. Published by Ernest Benn, Ltd., London, 1924, pp. 175–193, 2 figs., *dA*)

INTERNAL-COMBUSTION ENGINEERING

Flame Speed and Spark Intensity

A recent report of the National Advisory Committee for Aeronautics describes a series of experiments undertaken to determine whether or not the electrical characteristics of the igniting spark have any effect on rapidity of flame spread in the explosive gas mixture which it ignites. The results show clearly that no such effect exists. The flame velocity in carbon-monoxide-oxygen, acetylene-oxygen, and gasoline-air mixtures was found to be unaffected by changes in spark intensity from sparks which were barely able to ignite the mixture up to intense condenser-discharge sparks having 50 times this energy.

The experiments described in this report seem also to justify the following conclusions:

1 The ignition of explosive gas mixtures by jump sparks from an induction coil is produced by the initial or capacity component.

2 The normal rate of spread of the flame through initially quiescent gas mixtures is not affected by any change in the intensity of duration of the spark. This has been tried over the range of from 0.008 to 0.0003 sec. in duration, from 0.11 to less than 0.002 joule in total energy, from 0.02 to 0.0004 joule in the energy of the capacity component, and for flame speeds ranging from 200 cm. per sec. to 20,000 cm. per sec.

3 The flame speed produced by a "break spark" or arc in which the capacity component is absent is the same as for a jump spark.

4 In mixtures having normal rates of burning comparable with the velocity of sound, an abnormally rapid burning may be set up at the instant of ignition.

5 The tendency to burn in this manner is greater with long spark gaps and with increased secondary capacity. (D. W. Randolph and F. B. Silsbee, in Report No. 187, National Advisory Committee for Aeronautics, pp. 3–14, 7 figs., *e*)

A New Type of Engine for Large Aircraft

The author recommends the use of an 80-deg. W-type engine for 18 cylinders, claiming as its advantage the reduced frontal area, which is said to decrease as the stroke-to-bore ratio is reduced, this reduction being greater in the 80-deg. W-type than in either the 12 cylinder 60-deg. V-type or the 18-cylinder 40-deg. W-type. He illustrates this by a series of curves.

It is also stated that the 80-deg. W-type engine shows inherently more piston displacement per square foot of frontal area at the same stroke-to-bore ratio. In considering the influence of various piston displacements as resulting from changes in stroke-to-bore ratios upon the weight of the engine, the author comes to the conclusion supported by curves that the weight per horsepower decreases with an increase in piston displacement, the lowest values being found with the lowest stroke-to-bore ratio. (Glenn D. Angle in *Aviation*, vol. 17, no. 5, Aug. 4, 1924, pp. 832–834, 4 figs., *g*)

Worthington Two-Cycle Double-Acting Diesel Engine

This engine, the first of its design to be built, was demonstrated on August 28 at the Buffalo plant of the Worthington Pump and Machinery Corporation. It is rated at 600 to 800 hp. for a single-cylinder unit, at speeds of 90 to 120 r.p.m.

The main feature of the design is the cylinder. It slides in a cast-iron lining fitted into a chrome-vanadium forged-steel head at each end. The two heads are independent, and the different temperature expansion coefficients of the steel and the cast iron are compensated for in the design. Opposite the middle of the cylinder, arranged around one semicircle, are the exhaust ports, and in the other semi-circumference are scavenger ports for sweeping a volume of low-pressure air through one end of the cylinder as the cylinder is compressing the other end preparatory to receiving its fuel charge.

As the cylinder of the new engine is substantially equivalent to two single-acting cylinders opposed end for end and working in opposite directions, with their respective pistons flanged to the same rod, each stroke of the engine is a power stroke. The success of the design is attributed to the manner in which the problems of expansion and of heat removal were solved.

As regards the valve gear, there are three fuel spray valves, one on top of the upper end of the cylinder, and two in the bottom head on opposite sides of the piston rod and entering at an angle. Each of the three valves has its own cam, all three geared to the same shaft. The cams are symmetrical and to reverse it is only necessary to shift all three cams simultaneously through 34 deg. on the shaft. This is accomplished by a worm shaft, which in turn, is actuated by an oil-operated hydraulic mechanism controlled by a four-way cock, this, in turn, being operated by a single lever on the maneuvering platform. (*The Iron Age*, vol. 114, no. 10, Sept. 4, 1924, pp. 559–560, 2 figs., *d*)

The Relation of Fuel-Air Ratio to Engine Performance

Of the published information on the relation of fuel-air ratio to engine performance, little has been derived directly from tests of aviation engines. Nor have many tests been made at low air pressures and temperatures, conditions of major importance from an aviation standpoint. Much of the information that does relate directly to aviation problems is contained in Technical Reports Nos. 48, 49, and 108 of the National Advisory Committee for Aeronautics. The titles and authors of these reports are given in a brief bibliography at the end of the original article.

The purpose of this investigation was to ascertain from engine tests the answers to the following questions:

1 What gasoline-air ratio gives maximum power?

2 Is the value of this ratio appreciably affected by such changes in air pressure or temperature as are encountered in flight?

3 What percentage of its maximum power does an engine develop when supplied with a mixture giving minimum specific fuel consumption?

This report is based on tests made at the Bureau of Standards between October, 1919 and May, 1923. From these it is concluded that: (1) With gasoline as a fuel, maximum power is obtained with fuel-air mixtures of from 0.07 to 0.08 lb. of fuel per lb. of air; (2) maximum power is obtained with approximately the same ratio over the range of air pressures and temperatures encountered in flight; (3) nearly minimum specific fuel consumption is secured by decreasing the fuel content of the charge until the power is 95 per cent of its maximum value.

Presumably this information is of most direct value to the carburetor engineer. A carburetor should supply the engine with a suitable mixture. This report discusses what mixtures have been found suitable for various engines. It also furnishes the engine designer with a basis for estimating how much greater piston displacement an engine operating with a maximum-economy mixture should have than one operating with a maximum-power mixture in order for both to be capable of the same power development. (Stanwood W. Sparrow, Mem. A.S.M.E., in *National Advisory Committee for Aeronautics*, Report no. 189, 1924, pp. 3-16, 19 figs., *e*)

The Rolls-Royce "Condor," Series III

This engine appears to be of conventional design as far as the main lines are concerned, but includes a large number of new and interesting features. It is of the 12-cylinder water-cooled V-type with the cylinder banks placed at an angle of 60 deg. and with overhead valves operated by overhead camshafts driven by inclined tubular driving shafts from the rear end of the crankshaft. The cylinders are separately mounted on the crankcase and are of built-up all-steel construction. The water jackets are of die-pressed steel, acetylene-welded at the joints. There are four valves per cylinder, two inlet and two exhaust, all of the trumpet type and made from special high-chromium-steel forgings, and two spark plugs per cylinder.

There are only three cams for each four valves, the central cam operating the two inlet valves. The camshafts are enclosed in tubular steel casings carried between the valve cages and the rocker covers, and each camshaft runs in six split-type aluminum bearings.

The system of suspension is practically the equivalent of a 3-point suspension, the object being to lighten the mounting and to avoid transferring the torsional stresses to the crankcase. The reduction gear is a single spur-type bringing the center of the airscrew upward to a point almost exactly in the center of the frontal area of the engine. The gear-reduction ratio is 0.477, giving an airscrew speed at normal revolutions of 907 r.p.m. The airscrew is of metal with detachable blades.

As regards fuel consumption of the "Condor," the average during the 50 hr. of the Air Ministry type tests was found to be below 0.49 lb. per b.hp. per hr. The weight works out at just a fraction over 2 lb. per b.hp. at normal speed and power, and even less if the estimate is based on full-power conditions.

The connecting rods are forked not only over the crankpins but also one of each pair over its mate. They are of H-section and are made from $3^1/_2$ per cent nickel-steel forgings heat-treated to give a high Brinell number, and are machined all over to reduce weight variations.

The twin carburetor is of the Rolls-Royce Claudel-Hobson type, and is, as previously mentioned, mounted in a very low position so as to facilitate gravity feed. A special form of altitude control has been evolved for the "Condor," in which a conical valve rotates in a conical seating ground to fit. The seating has two fairly wide slots, while the valve has two small holes, diametrically placed, from one of which runs a hair-thin circumferential slot. This valve is incorporated in a lead between float chamber and jet, and by rotating the valve the pilot regulates the amount of gasoline allowed to run from float chamber to jet. The reason for a single slot instead of two placed symmetrically is that it would have been almost impossible to make the slots sufficiently narrow.

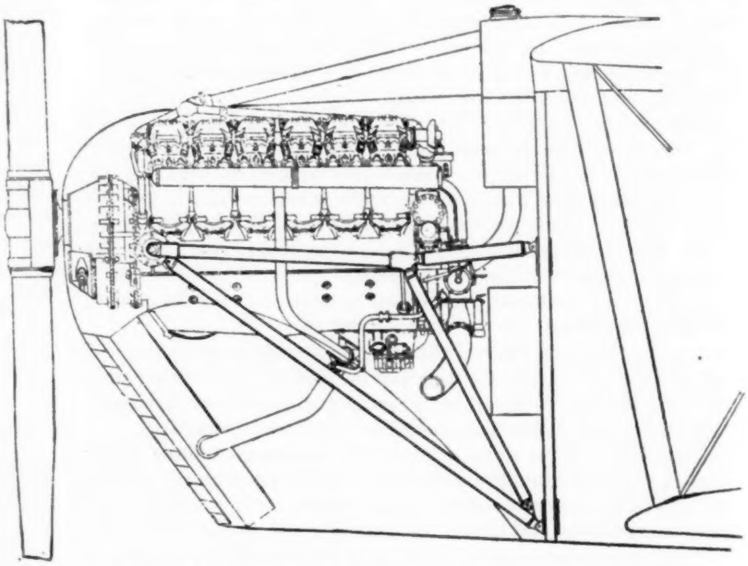


Fig. 1 Mounting for the Rolls-Royce "Condor" Engine

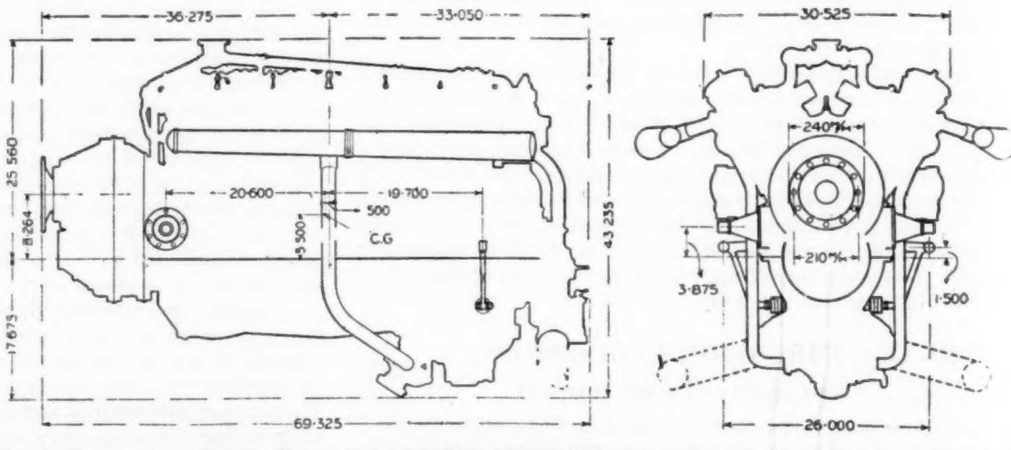


Fig. 2 Dimensioned Sketch Diagram of the Rolls-Royce "Condor" Engine Giving Some of the More Important Measurements

The new type of altitude control would appear to be of very simple and robust form, as there does not seem to be anything in it which could possibly go wrong. Special compensating passages are provided in the carburetor which maintain under all conditions the same pressure in the float chamber as in the throat, thus neutralizing eddy-current effects. The induction pipes are of large diameter and are formed with easy bends. They are water-jacketed at the carburetor end. The air intakes are bolted to the lower end of the carburetor, and can be easily brought right outside the engine cowling, and as the system is self-draining there should be very little chance of fire. Above the carburetor is mounted a distributer for use in conjunction with a gas starter, pipes running from the distributer to all the cylinders.

It may be mentioned that the throttle and ignition controls have been interconnected in such a way that the spark is advanced as the throttle is opened, up to about three-quarter full throttle. Then a further advance of the throttle lever slightly retards the

spark. The main throttle is also connected to the altitude control in such a way that the pilot, in throttling down, automatically closes the altitude compensator, which latter cannot, therefore, accidentally be left "on." Another advantage of this arrangement is that but two engine controls have to be taken through the fire-proof bulkhead.

The mounting of the Rolls-Royce "Condor" series III (Fig. 1), is of unusual type in that no longitudinal bearers are required. Near the front corners of the upper half of the crankcase are two cylindrical lugs cast integral with it, and to these are bolted conical steel trunnions that serve as supports for the front part of the engine. The rear supports are in the form of two cranks whose lower arms are connected by a bar running through the crankcase. Short rubber buffers are incorporated so as to allow of a certain amount of play. The outer, or free, ends of the cranks are bolted to the airplane framework. It will be seen that torsional stresses are taken at a point very close to the airscrew, and that a minimum of stress is transmitted through the crankcase. The rear system of links is similar to that used for a long time on Rolls-Royce cars, and is the equivalent of three-point suspension.

A dimensioned sketch diagram of the "Condor" giving some of the more important measurements will be found in Fig. 2. (*Flight*, vol. 16, no. 815/32, Aug. 7, 1924, pp. 494–500, illustrated, *dA*)

LUBRICATION

Concerning the Value and Use of Characteristics of Lubricating Oils

The author considers the characteristic properties of lubricating oils mainly with regard to their value as elements of specifications. He comes to the conclusion that none of the tests to which lubricating oils are usually subjected is in itself sufficient to determine the stability of an oil for a given purpose.

It might be supposed at first sight that a combination of several tests would be sufficient for determining the oil specification, but actual experience proves that this is not so. What specifications do is to eliminate products which are obviously unsuitable for the service in question, but once this elimination has been made there may be a number of products of different qualities, all of which may satisfy the requirements of specifications and yet not be suitable for a given purpose.

In any event specifications should avoid demanding from an oil a combination of characteristics which cannot exist at the same time—for example, a very low freezing point for an oil of very high viscosity. It also happens quite often that in specifications, conditions are given an improper value, so that, for example, in an oil used for the lubrication of a transmission the ignition point is given the same importance as viscosity, while viscosity at 20 deg. cent. (68 deg. fahr.) is specified for an oil used for engine-cylinder lubrication.

In order to show how products of very different quality can be offered to satisfy a specification, the following two examples are cited.

Example 1. An important concern wanted to purchase an oil for lubricating gas-engine cylinders and gave the following specification:

Engler viscosity at 50 deg. cent.	10
Ignition point	210 deg. cent. (140 deg. fahr.)
Combustion point	245 deg. cent. (473 deg. fahr.)

Among the oils which would satisfy this specification there was a high-grade automobile cylinder oil and also a very common-grade black oil suitable only for such purposes as oiling horse-drawn vehicles. Its characteristics were, however,

Engler viscosity at 50 deg. cent.	12.15
Ignition point	233 deg. cent. (451.4 deg. fahr.)

As a matter of fact, neither of the two oils was suitable for the given purpose and certainly black horse-wagon oil would not be used for lubricating a gas-engine cylinder, and yet both oils answer the specification.

Example 2. A French works recommends for lubricating steam-engine cylinders of their make oils answering the following specification:

Density	0.89 to 0.92
Engler viscosity at 50 deg. cent. (122 deg. fahr.)	38 to 42
Engler viscosity at 100 deg. cent. (212 deg. fahr.)	2.7 to 2.5
Ignition point	230 to 320 deg. cent.

Now it is obvious that the viscosity of an oil at 50 deg. cent. has no importance whatsoever for lubrication steam-engine cylinders, and moreover the values of the viscosity at 50 deg. are so high as compared with viscosity at 100 deg. cent. that actually only oils of very inferior quality would satisfy these conditions. The higher-grade oils are automatically excluded, because the better the oil the slower its viscosity falls away with temperature.

It would appear, therefore, that general specifications are as a rule incapable of determining the choice of an oil for a given set of conditions. Furthermore, specifications are sometimes dangerous, because they may lead to the employment of entirely unsuitable products and, in turn, may have grave consequences. In the actual state of our knowledge it is impossible to determine the suitability of a lubricant otherwise than by an extensive test on the machine on which it is to be employed. It is not a quick method of determination, but unfortunately it is the only reliable one until work in the laboratory gives more information as to properties of lubricants than we have in our possession today. (Engr. Piessevaux, in *Revue Universelle des Mines*, 7 Series, vol. 3, no. 8, Aug. 1, 1924, pp. 153–163, *p*)

METALLURGY

A New Process of Sulphur-Print Macrography

According to the author, the disadvantage of the well-known Baumann process of making sulphur prints lies in the fact that the image, obtained by this process on paper, cannot be used directly for enlargement because it is not transparent. In reproduction the details do not come out well and the comparatively coarse grain of the paper does not lend itself well to enlargement. The difference between the Baumann process and the process suggested by the author lies in the use by the latter of a transparent fine-grained support such as made of a photographic (sulphur bromide) plate or film, and the author shows an original macrograph which was obtained by direct impression on a film and an enlargement thereof. (Jean Durand in *Le Génie Civil*, vol. 85, no. 6, Aug. 9, 1924, pp. 131–133, 6 figs., *d*)

MOTOR-CAR ENGINEERING

California Air-Cleaner Tests, 1924 Series

References are made to published results of similar tests of air-cleaner devices conducted in 1922, and the scope of the 1924 tests is described. Road tests of air cleaners were carried out and tabulated data are presented. Efforts were made to find out how much dust the engine would draw in if the cleaner and connections were removed, and to catch and to weigh the dust the air cleaner being tested failed to catch.

Dust was raised by a car running about 50 ft. ahead of the test-car and, to produce heavy dust conditions, it dragged the road with a chain attached to form a loop behind it. The leading drivers maintained as nearly as possible a constant speed of 25 m.p.h. and chose the dustiest part of the road, following the same course in all the rounds.

The specific items of the 1924 programs were (*a*) to continue the testing work begun in 1922, (*b*) to devise a satisfactory method of test for types of air cleaner that cannot well be tested by the 1922 method, (*c*) to determine how much dust an automobile or truck encounters in service, and (*d*) to find out how the use of air cleaners affects the rate of engine wear.

After describing the "absolute" air cleaner used in connection with the air cleaners being tested, standard dust for testing purposes and Fuller's earth are discussed, inclusive of some tests made of the latter substance. Road tests are treated generally and specifically, road-test and laboratory-test comparisons are made and the 32 air cleaners submitted for test are described, together with tabular data of the results obtained while testing them. (A. H. Hoffman, Agricultural Engineering Div., University of California, Davis, Cal., in *The Journal of the Society of Automotive Engineers*, vol. 15, no. 2, August, 1924, pp. 140–148, 8 figs., 8 tables, *e*)

POWER-PLANT ENGINEERING

Electrolytic Protection of Boilers

THE idea of protecting boilers from corrosion by electrolytic means is not new and parallels the development of processes for oil separation from feedwater by electrolytic means which have been successfully adopted in a number of German plants.

In marine boilers supplied with distilled water and in condensers cooled by the circulation of sea water an attempt has been made to inhibit the formation of scale deposits and corrosion by suspending zinc plates in the water. This process was first proposed by Cumberland and became the basis for the development of the so-called Siemens Electrolytic Boiler Protection Process. In this latter an anode insulated from the container, such as water tank or boiler, was introduced into the latter and connected with the positive pole of an electric generator, while the container itself was connected with the negative pole, thus forming a cathode. There are two other processes of a somewhat similar character, namely, the Renger-Fuhrman and the "Currentless."

As a matter of fact, there is still a good deal of doubt as to how far electrochemical processes are capable of displacing mechanical, chemical, or thermal processes, and, in particular, some of the leading German concerns engaged in water purification have expressed either doubts or lack of conviction as to electrolytic processes. The present article gives data as to the actual performances of one such process, namely, the Renger-Fuhrman.

This process also consists in the application of a low-voltage direct current to the water container, such as tank or boiler, but differs from the Siemens process in that the direct introduction of the anode into the container is eliminated. In this process the boiler is electrically inserted between the negative pole of a direct-current generator and an aggregate of electrodes consisting of positive and negative electrodes which may be located in any container, for example, the feedwater tank, forming part of the negative circuit. The current, such as that generated by a low-voltage dynamo, flows then from the positive pole of the dynamo to the positive electrode, thence through the water to the negative electrodes, whence it flows through an electric conductor to the boiler wall. Here several connections are provided and distributed in accordance with certain rules for the return of the current to the negative terminal of the dynamo. The actual installation consists of an electrolyzer with electrode plates—which may be made of old iron, a current generator such as a dynamo delivering current at 15 to 20 volts, various circuits at the boiler, and the usual electrical equipment. The electric power consumption is said to be from 1 to 2 watts per sq. m. (0.1 to 0.2 watts per sq. ft.) of heating surface, while the consumption of materials is said to be extremely small.

The process has been installed in a considerable number of boiler plants of various sizes. The following presents data as to some of these installations.

In a certain textile mill there is a single-header water-tube boiler having 304 sq. m. (3272 sq. ft.) of heating surface, 10 atmos. gage pressure and an economizer. The electrode tank is of about 6 cu. m. (211.8 cu. ft.) content; the feedwater has a total hardness of 4.04 deg., leaving a residual hardness of 3.62 deg. (One German degree of hardness is equivalent to the content of 1 mg. of CaO in one liter of water); the feedwater is preheated in the feedwater tank to about 26 deg. cent. (78.8 deg. fahr.) by exhaust and water of condensation; the temperature beyond the economizer is about 87 deg. cent. (188.6 deg. fahr.). The test started on November 2, 1922, and ended March 17, 1923, its duration being 1088 hr.; feedwater consumption, 3370 cu. m. (118909 cu. ft.); evaporation, 3020 kg. per hr., equivalent to about 10 kg. per sq. m. (2 lb. per sq. ft.). Electrical equipment, 39 electrode plates of a total area of 15.7 sq. m. (167 sq. ft.); generator potential, 15 volts; total current, 29 to 30 amperes; current distribution; 2 leads to the upper drum, each carrying about six amperes; front part of water header, 8.5 amperes; two leads to the left and right upper drum carrying, respectively, 5.5 and 5.6 amperes, and one lead to the rear of the water header broken and therefore carrying no current.

In accordance with the report of the representative of the local Boiler Inspection Association the condition of the boiler at the commencement of the test, October 27, 1922, was substantially as follows: Forty-five pipes were renewed, including all of the lower rows of pipes. The boiler was well cleaned out. The old tubes were comparatively clean, although in the front half there was a certain amount of incrustation. At some spots on the shell plates there was present a thin layer of boiler scale from 2 mm. to a maximum of 5 mm. (0.08 to 0.2 in.) thick, but otherwise they were practically free of scale.

The condition of the boiler after the completion of the test on March 26, 1923, and before cleaning, was, according to the report of the same association, substantially as follows: The tubes were found to be practically clean with only bits of boiler scale at the ends. In the upper drum, looked at from in front, there was found on the water-wetted surface a sandy deposit, perhaps 1.5 mm. (0.06 in.) thick, which was easily removed by scraping. The places from which scale was removed before the test could no longer be distinguished, notwithstanding the comparatively thin layer of deposit. No mud or bits of boiler scale were found in the upper drum. The old boiler scale was not dissolved. In the upper left drum there was no deposit on the last two shell plates, i.e., within the region where the feedwater pipe does not reach. But at the end of the third seam there were found about a couple of handfuls of pieces of boiler scale. As regards the front space, there was found in the water space over the whole width of the plate a layer of sandy scale up to 8 mm. (0.32 in.) thick but this scale was very fragile and was easily removed by scraping, and sometimes it could be broken between the fingers. The old boiler scale, however, did not seem to be affected.

The second installation described had a corrugated-flue-tube boiler of 70 sq. m. (817 sq. ft.) heating surface, with an evaporation of about 7 kg. per sq. m. (1.4 lb. per sq. ft.) per hr. The feedwater had a total hardness of 6.60 deg., and a carbonate hardness of 0.84, leaving a residual hardness of 5.76, and was heated by water of condensation to about 40 deg. cent. (104 deg. fahr.). The electrical equipment consisted of four electrode plates, 2 sq. m. in area, located in the feedwater tank. The generator potential at the beginning of the test was 10.7 volts; and the potential at the electrodes, 6.7 volts. The total current was 4.6 amperes, distributed as follows: One connection in the front part of the boiler, 1.5 amperes; in the rear part of the boiler, 1.3 amperes; and at the flue, 1.8 amperes. At the end of three months the generator potential fell to 8 volts and the current rose from 7 to 11 amperes; after $4^1/_2$ months of test a larger generator was installed, raising the generator potential to 15 volts, the potential at the electrodes to 14 volts, and the total current to 15 amperes.

According to the report of the Boiler Inspection Association, the boiler was started without cleaning. On the jacket below the lowest water level there was a thin-skinned scale and a similar scale in the front part of the body. At the flue there was scale varying in thickness from 0.5 to 1.5 mm. (0.02 to 0.06 in.), also scale in several other places. This was the condition when the test started on September 28, 1921.

On November 15, 1921, it was found that there was very little improvement, the scale condition being practically the same as at the earlier date, but on January 17, 1922, it was found that the process worked out so well that in the first ring of the flue a good deal of the scale had become brittle and could be easily removed by hammering. Elsewhere, however, there was little of the process observable. No new scale formed, and at the bottom of the boiler there was a considerable amount of mud.

Further progress was noticed during an inspection on May 3, 1922, it being found that the scale practically everywhere could be knocked off with an ordinary hammer. There was no new scale formation, but there were about six bucketfuls of mud at the bottom of the boiler, and the condition was found to be still better on September 12, 1922, thus indicating that in this instance at least the process had proved to be highly successful.

The third installation described was a steel works in which the electrolytic protection was applied to a Lancashire boiler with a heating surface of 80 sq. m. (861 sq. ft.) and an evaporation of 10 kg. per sq. m. (2 lb. per sq. ft.) per hr. The feedwater was taken from a river and was found to contain 6.3 deg. of total hardness and 3.3 deg. of carbonate hardness. After a year's operation it was found that there was a layer of scale 4 mm. (0.16 in.) thick of rather loose consistency.

The boiler was placed in operation on March 7, 1922, and electrolytic protection applied on June 11, 1922. On July 28, 1922, it was found that the jacket was free of scale, the old scale having broken off, and that no new scale had formed on the flues.

This was considered to be so encouraging that two other boilers were equipped with electrolytic protection, with the rather surprising result that when one of the additional boilers was opened on June 14, 1923, it was found that the walls were covered with as thick a layer of scale as before the process was applied. The same result was obtained on October 24, 1923, for one of the two boilers equipped with protection at a later date.

Efforts to prevent corrosion in boilers by the application of the Renger-Fuhrman process did not prove to be successful. Neither was the process uniformly successful in preventing scale formation, although it did produce results under certain favorable conditions, such as size of the boiler not excessively large, water not too hard, and with prevalence of carbonate hardness together with absence of silicic acid and organic matter. (Dr. Hermann Manz. *Die Wärme*, vol. 27, no. 28, July 11, 1924, pp. 325–327. First installment of a serial article, *de*)

RAILROAD ENGINEERING (See also Corrosion)

Uniflow Locomotives in Germany

THE first locomotive in which the uniflow principle was applied was a superheater freight locomotive built for the German State Railways in 1920 by A. Borsig, Berlin. This locomotive did not prove to be a success as it was found that while it was more economical than the compound for small loads, its fuel consumption was higher at high loads. The locomotive was equipped with horizontal single-beat poppet valves, which were found objectionable because of the high lift and large force required to raise the valve. On the whole, from the experience with that locomotive which ran for three years, it was concluded that the future line of progress of the uniflow locomotive would be in the three-cylinder type with cylinders having small clearance volume, and utilization of the ejector action of the exhaust, in combination with high pressure and modern superheat.

In the next locomotive the single-beat valves were replaced by a positively controlled piston valve allowing for an additional exhaust, which partially followed upon the main exhaust controlled by the piston.

The original article illustrates by means of an indicator diagram the advantage gained thereby. The design of the cylinders and exhaust pipe is also described and illustrated in detail in the original article.

After the union of the three exhausts of each cylinder both united exhaust pipes become a combined ejector, so that the exhaust of each cylinder evacuates the other. By this arrangement the speed energy of one cylinder will evacuate its own cylinder as well as the other, the active steam thus mixing with the passive steam at two places and equalizing the speed of the steam through the exhaust pipes to a large extent. This equalization is continued in the nozzle which transforms the speed energy into pressure energy, thus utilizing any remaining energy that may be left from the exhausts. The result is a fairly equalized flow of steam from the mouth of the nozzle, which tends to create a uniform draft upon the flue gases, resulting in good combustion and a good production of steam. There has never been the slightest complaint of any kind about lack of steam.

Further examination of the results in testing this peculiar suction exhaust showed a surprisingly low vacuum in the smokebox, that the fireman carried an unusually light fire, and that there was little surplus air and a relatively small amount of carbon monoxide. There was also considerable moist steam at the mouth of the stack, which showed that the steam was performing an increased amount of work. This increased work is shown in Fig. 3 by the shaded area below the atmospheric line, which, however, amounts only to 14 per cent of the lost work represented by the shaded area above the atmospheric line. It also showed that the suction exhaust was working with an extremely bad efficiency, which opens the prospect of realizing a much better vacuum if proper measures to that end are taken. In fact, a vacuum of 80 per cent should be easily attainable. This design can be improved in a great many ways; for example, the spider placed in the mouth of the nozzle should be removed in order to give more area for the exit of the flue gases.

In the last paragraph of the article the author raises the question as to what field is available for the condensing-turbine locomotive if there should be a vacuum produced with the uniflow system for a medium and long cut-off equal to that of a turbine locomotive equipped with a condensing device. (Prof. J. Stumpf, Berlin, Germany, in *Railway Age*, vol. 77, no. 8, Aug. 23, 1924, pp. 327–331, 8 figs., *d*)

Turbine Locomotives

A GENERAL discussion of several types, all of which have been described before. The locomotive built at the Escher-Wyss works in Zurich in accordance with the designs of Dr. Zoelly, however, is not as well known as the rest.

In this locomotive a boiler of the usual type is used. Two turbines are installed on the front part of the frame, one of them being used for driving ahead and the other for reversing. Both operate on the same shaft located transversely to the axis of the locomotive, the power being transmitted from the turbine by a gear wheel to an intermediary shaft and the wheels are driven in the usual manner. Behind the turbines and under the boiler is installed a surface condenser, the cooling water being delivered from the tender where apparatus is installed for cooling the condensed water. This apparatus consists of a system of pipes with numerous holes through which water escapes in a fine rain. The cooling is produced by the intimate contact of the small drops with air while the engine is running. Because of the losses it has been found that the amount of cooling water that has to be carried is equal to about one-half of the water necessary for feeding the boiler.

This locomotive is now under test but the results have not yet been published. It is significant, however, that the Krupp Company of Essen has acquired the German rights for building this locomotive, as well as the rights to supply it in several other countries. (Lamy, Engineer of the Paris-Lyon Méditerranée, in *La Revue Industrielle*, vol. 54, no. 2181 (New Series no. 33), August, 1924, pp. 217–221, 7 figs., *dg*)

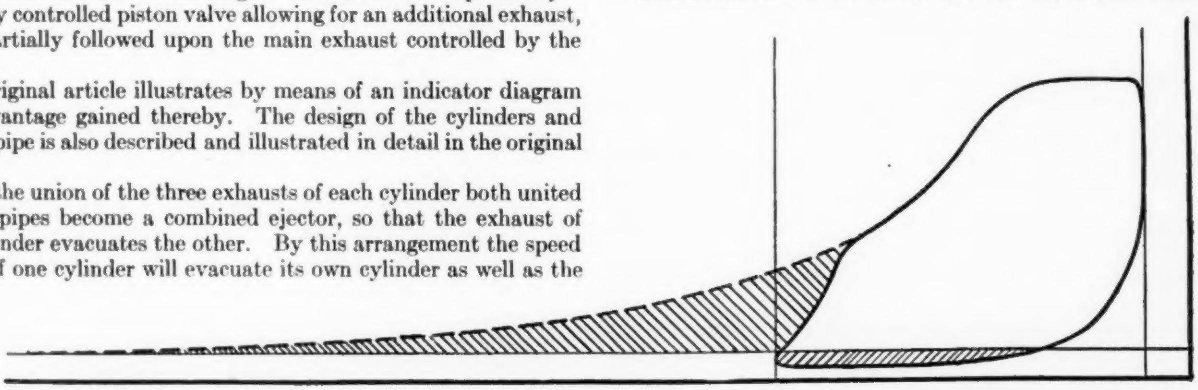


FIG. 3 A THEORETICAL INDICATOR CARD IN WHICH THE SHADED AREA BELOW THE ATMOSPHERIC LINE SHOWS THE GAIN IN PRESSURE ENERGY DUE TO EXHAUST EJECTOR ACTION

SAFETY ENGINEERING (See Air Engineering)

CLASSIFICATION OF ARTICLES

Articles appearing in the Survey are classified as *c* comparative; *d* descriptive; *e* experimental; *g* general, *h* historical; *m* mathematical; *p* practical; *s* statistical; *t* theoretical. Articles of especial merit are rated *A* by the reviewer. Opinions expressed are those of the reviewer, not of the Society.

Correspondence

CONTRIBUTIONS to the Correspondence Department of Mechanical Engineering are solicited. Contributions particularly welcomed are discussions of papers published in this journal, brief articles of current interest to mechanical engineers, or comments from members of The American Society of Mechanical Engineers on activities or policies of the Society in Research and Standardization.

The Hardness of Metals and Hardness Testing

To the Editor:

On reviewing the attempts which have been made to measure hardness, we find that the methods employed do not give results which are a dimensional property of the material. That is, these results cannot be expressed in a rational term which is the product of two or more of the real powers of the fundamental physical units of length, time, force, and mass. For instance, Moh's scale of hardness gives a list of ten minerals, each of which can be scratched by the next harder and can scratch the next softer. This is not a method of measuring hardness, but merely a method of comparing the relative hardness of two substances differing widely in hardness. When substances do not differ markedly in hardness we find that in some cases each will scratch the other and in some cases neither will scratch the other. Moh's scale gives us only a rough idea of the relative hardness of a substance, and is obviously not based on any dimensional system. It is like saying that a man is bigger than a dog, but not so big as a horse.

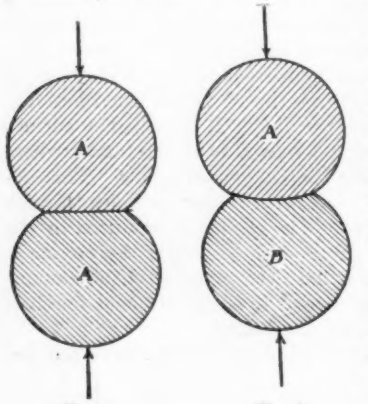


Fig. 1 Two Equal Spheres of Equal Rigidity Pressed Together

Fig. 2 Two Equal Spheres Pressed Together—*A* of Greater Rigidity than *B*

While we have no accepted definition for hardness, and while the property is extremely vague in the minds of most people, still it may not be impossible to identify it with some dimensional property of material. The following line of reasoning may serve to clear up the situation to some extent.

When two bodies of the same size and form, and so disposed that their plane of contact is a plane of symmetry between them, are pressed together, the stresses and distortions produced in each will be equal, if they are of identical materials. The simplest case is of course where two equal spheres are pressed together. If the spheres are of identical physical properties, the area of contact between them will be a plane surface and circular in form. A section through them may be seen in Fig. 1. The bodies will be equal in hardness and the stresses and temporary and permanent deformations produced will be the same in each. If we take two spheres otherwise equal but of unequal elastic moduli and press them together, the area of contact will be a limited portion of a surface of revolution, and concave toward the center of the more rigid sphere, as in Fig. 2. The normal pressure at any point in the surface of contact will be the same for both spheres. If the elastic limit is the same for both materials and the pressure is increased till the elastic limit is exceeded, both spheres will be permanently deformed; but it is obvious that the one having the lower modulus of elasticity will be deformed more than the one having the higher modulus of elasticity.

Similarly, if two spheres of unequal moduli of elasticity are pressed upon a third one of much higher modulus of elasticity and elastic limit than either of the first two, the one having the lower modulus of elasticity will be deformed the most. This is illustrated in Fig. 3.

From this the writer concludes that one of the dimensional properties of which hardness is a function is the modulus of elasticity, and the higher the modulus of elasticity of a material, the greater its hardness will be.

Let us return to our first line of reasoning and consider two spheres of equal moduli of elasticity but of unequal elastic limits, to be pressed together. Until the elastic limit of the weaker sphere is reached, the area of contact remains a plane circle. As soon as the elastic limit of the weaker sphere is passed, the area of contact ceases to be a plane circle and becomes concave toward the center of the stronger sphere, as shown in Fig. 4. When the pressure is removed, if the elastic limit of the stronger sphere has not been exceeded, it will return to its original form, while the weaker one will be permanently deformed. If the elastic limit of both materials has been exceeded, both of the spheres will be deformed, the weaker one, however, suffering the greater deformation. Hence we may conclude that the hardness of a material is a function of its elastic limit, and more specifically of its compression elastic limit.

The investigation of the result of pressing together two spheres

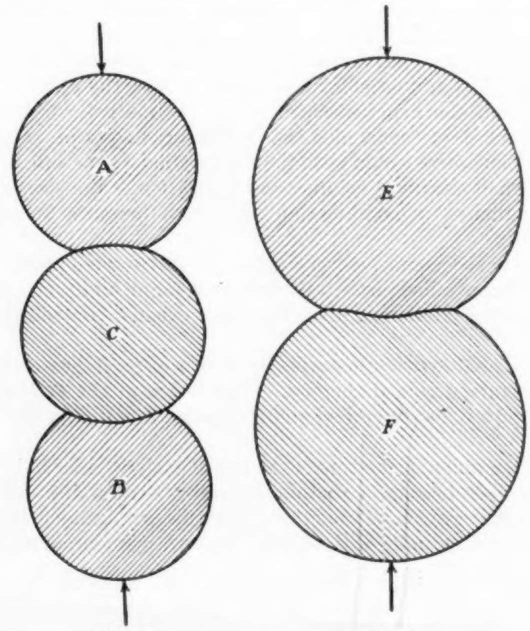


Fig. 3 Three Spheres of Unequal Rigidity Pressed Together, *C* Being the Most and *B* the Least Rigid

Fig. 4 Two Spheres of Equal Rigidity but of Unequal Elastic Limits, Pressed Together. Elastic Limit of *E* Higher than that of *F*—Elastic Limit of *F* Being Exceeded

of unequal elastic moduli and unequal elastic limits is a rather complicated mathematical problem. If we assume that the more rigid sphere has the lower elastic limit, we will observe the following phenomena as the pressure is increased:

Until the elastic limit of the weaker sphere is reached, the area of contact will be a curved surface concave toward the center of the more rigid but weaker of the two spheres. As the pressure increases, the elastic limit will finally be reached at the center of the surface of contact. Since the material there is supported by the surrounding material, the stresses are partly hydrostatic and partly shearing in their nature, and permanent deformation will not occur until the shear elastic limit has been passed. Because of its greater deformation this point may be reached first in the case of the stronger but less rigid sphere.

It is possible that the behavior of the two spheres under the con-

ditions of this experiment will not be controlled exclusively by their respective elastic limits and moduli, but will also be dependent on the forms of that portion of their stress-strain diagrams lying just beyond the elastic limit. In such a case the problem of making hardness a function of dimensional properties becomes rather hopeless. Furthermore it will probably be impossible to obtain consistent results when attempting to arrange a number of materials in a definite order of hardness when each is tested against all of the others, which is the simplest of all the problems in connection with the determination of hardness.

The logical solution of the difficulty seems to be to take the principal dimensional properties involved in the idea of hardness, to write an equation of rational form connecting these properties with a numerical value for hardness, to determine experimentally whether this equation is consistent, and the value of its constants, and to accept this equation as the definition of hardness. It is obvious that the principal dimensional properties affecting the hardness of a homogeneous material are its elastic limit and modulus of elasticity. The simplest form of equation that we can write connecting hardness with these properties is

$$H = C\,E^m L^n$$

where H = numerical value of hardness
C = a constant
E = modulus of elasticity
L = compression elastic limit
m, n = small positive real indices.

If now we prepare spheres of a number of different materials and investigate their behavior under the sort of test just described, we may determine the values of m and n, and obtain a rational definition of hardness. It is probable that the values of both m and n lie pretty close to unity.

The acceptance of this definition, or of a definition arrived at by a similar process of reasoning, would place the study of the subject of hardness on an entirely different basis, and eliminate most of the difficulties which are encountered in connection with it.

It may be objected that the behavior of certain materials contradicts the above theory. Glass, for instance, has a lower ultimate strength than the elastic limit of soft steel, yet it will scratch soft steel. The writer has given this matter some thought and it occurs to him that the explanation of the matter may lie in the following:

It has been found that in all crystalline substances the atoms are arranged in certain geometric patterns. When the atomic structure of glass is studied, it is found that the atoms are not arranged in any geometric pattern, but apparently individual molecules of the separate substances composing the glass are tumbled together in a heterogeneous manner. Physicists claim that this heterogeneous structure is the cause of the unusual brittleness of glass, and of the differences in its behavior under stress from that of steel and other metals which are essentially crystalline in their structure. According to the accepted theory of the atomic structure of solids, a strain in a crystalline solid is the result of a distorted atomic pattern. The strain extends as far as the deformation of the pattern, and changes in type and intensity in accordance with the amount and direction of the deformation of the pattern. It follows that a total lack of pattern represents a case in which strains of all types and intensities extend for minute distances in every direction. Such a solid will of necessity be extremely brittle, as is glass. When a load is applied to it, the strain and the associated stress produced by the load is added to that already existing, and the material breaks at a high intensity of localized stress, although the theoretical intensity of stress by the load was relatively low.

An analogy to this may be seen in the case of highly tempered high-carbon steels, which are extremely hard and yet, when tested, appear to be weak. If the broken parts are then ground to form smaller test pieces, their strength will be found to be very high, indicating that the weakness was due to internal strain rather than to lack of cohesive power.

In view of the above facts, we may be warranted in holding to the equation given, in the case of all materials of crystalline structure which are capable of plastic deformation, and in ignoring those extremely brittle materials of amorphous structure on the ground that we have available no real information with regard to their elastic limits.

Whether or not the reader agrees with the conclusions arrived at by the writer, he must admit that hardness and its measurement form a problem of ever-increasing interest and importance in scientific and engineering work. We cannot continue to progress in certain lines unless we arrive at some rational solution of the problem. The problem is of such importance as to deserve serious and intensive work of a fundamental nature. It is time for us to stop inventing new tests, and to agree on some fundamental definition which is susceptible of mathematical expression. The definition and method of testing it which the writer has sketched here outlined promises at least to determine in some measure the outline of the field of work, and the work should be undertaken just as soon as possible.

Forrest E. Cardullo.

Cincinnati, Ohio.

Notes on Hardness Tests

To the Editor:

There is no doubt that the term hardness is a very vague one. Unwin[1] stated the case very well in saying that the physicists doubted the existence of a definable quality such as hardness. We speak of hardness as referring to resistance to abrasion, cutting or indentation and in this sense apply the term in a very loose manner indeed. This misuse of the term hardness probably arises from the fact that our conception of it is not based on fundamental data but as in the impact test is based on relative results. In the hardness tests we have an unknown stress distribution and since it appears that it will always be impossible to determine these stresses, the hardness test is likely to remain relative only. While this is so, however, it does not appear justifiable that we should delete the term hardness but that we should rather be more specific and speak of static indentation hardness, dynamic indentation hardness, or scratch hardness as the case may be.

The most important hardness test from the engineer's point of view is of course the static indentation test made either as proposed by Brinell by using a ball, or by Ludwick by using a cone. Originally the use of the ball was limited but Meyer's[2] work on the subject has broadened its scope considerably.

The scratch test discussed by Martens and later by Hadfield and now developed further by Hawkins[3] is immensely interesting. The test is, however, new to the engineer and at present more knowledge is required regarding it.

Similarly with the pendulum test we have again a new method. In this case the hardness is determined from the time of oscillation of the instrument which is in the form of a pendulum. There appears to be a simple relation between the time hardness and the Brinell indentation hardness. If H is the Brinell hardness and T is the time hardness then

$$H = 10T \text{ for } T > 33^1/_3$$

$$H = 0.3T^2 \text{ for } T < 33^1/_3$$

It appears, however, from these different relations that there is much still to be learned about the characteristics of the test. That it is of value there is no doubt because since the complete instrument weighs only either two or four kilograms it can be used to determine the hardness of thin and fragile materials which could otherwise not be tested. The carrying out of further investigations by the use of this instrument is therefore to be encouraged since these may give us clearer ideas on just what the indentation test really is.

J. M. Lessells.

East Pittsburgh, Pa.

[1] Mechanical Properties of Materials, *Proceedings Institute of Mechanical Engineering*, Oct., 1916.

[2] *Zeit. Ver. Deut. Ingen.*, 1908.

[3] Scratch Hardness Test, *Proceedings Institute of Mechanical Engineering*, p. 423, 1923.

Research in Cutting Metals

To the Editor:

The writer has read with considerable interest Professor Airey's letter on The Present Status and Future Problems of the Art of Cutting Metals, published in the March number of Mechanical Engineering. There is some question, however, whether his recommendations that the studies should be along the lines of determining the energy required for different tools under various cutting conditions would lead to results of value. What are wanted, of course, are the laws governing the cutting life of the tool, and the temperature rise at the point of the tool is probably the principal factor. It is also undoubtedly true that the energy used goes into heat, but whether or not there is any close correlation between this heat quantity and the temperature at the wearing edge is, in the opinion of the writer, something which as yet remains to be proved.

Fred W. Taylor states in Par. 505 of The Art of Cutting Metals that no law can be formulated which expresses the relation between cutting speed (that is, the cutting speed which will bring the tool to the point of destruction in the allowed cutting time) and the pressure on the tool. As the energy at the tool is given by the product of the pressure and the cutting speed, the statement might be reworded to say that there is no relation between the energy which is required and the life of the cutting tool. As this statement is backed up by a considerable amount of experimental work, the factors involved and the conclusion stated should be seriously considered.

Taylor points out that the heat is broadly proportional to the pressure on the tool, the cutting speed, and the coefficient of friction between the chip and the tool. Now the greater part of the energy required in cutting probably goes into deforming the chip, thus raising its temperature, and this raises the question whether the increased temperature of the tool is due more to the conduction of heat from the chip or to heat generated by friction between the chip and the tool. Variations in the relations between these two may vitally affect the correlation between total energy and temperature at the edge of the tool.

Another difficulty arises from the fact that the coefficient of friction probably varies between the condition of high intensity of pressure with hard metals and a lower intensity with soft metals where the chip deforms greatly, while the total energy required for each cut may be the same.

Furthermore, the temperature at the cutting and wearing edge of the tool is probably affected by the area of contact between the chip and the tool and by the location of this area with reference to the cutting edge. In other words, the temperature rise would be much greater for hard steel where the pressure is concentrated near the cutting edge than for mild steel where the center of pressure is much further away due to the deforming of the chip. Even where the same metal is considered, similar differences might occur due to changes in the shape of the chip caused by a different combination of feed and depth of cut.

Finally, temperature rise may not be the predominating cause of tool failure. Taylor mentions the abrasive action of the material which is being cut as another cause and assigns it as the reason why tools used in cutting cast iron have a smaller rise in temperature than those used in cutting mild steel and yet wear out more rapidly.

In view of the statements of Fred W. Taylor and the above analysis based on them, the writer feels that studies in the relation between energy required and metal removed, as suggested by Professor Airey, may be quite barren of results as far as the determination of the laws governing the cutting life of the tools is concerned, unless these tests are carried to the point of the destruction of the tool. If a sufficient number of such tests are made, it will be possible to either verify or contradict Taylor's conclusion quoted at the beginning of this discussion. When this has been done the decision can properly be made whether to carry out Professor Airey's suggestion or simply to record energy required as an incidental, but important, figure in actual test of tool cutting life.

James A. Hall.

Providence, R. I.

Shall There Be Clothing Engineers?

To the Editor:

Under this title the *Clothier and Furnisher* editorially endorses a plan of the International Association of Clothing Designers to create a "Bureau of Engineering." Quoting from the editorial: "When we stop to analyze the clothing industry we must come to the conclusion that the designers are really engineers. Just as in the mechanical field those who design, perfect and construct machinery are known as engineers, so are those who design, perfect and construct clothing in the same sense engineers."

The engineer, who at one time or another has had ferrous fittings attached to clothes that must be washed, or has seen snap fasteners used when the load on them is not in shear or is of such a magnitude that the safety factor is about one, or has stopped to consider why buttons are placed on coat sleeves or why styles are devised which "take" and pass out before wearing out, must come to the conclusion that Clothing Designing is not Engineering.

Perhaps it is an Art. Perhaps there is some Science required to practice it. Perhaps it requires an extensive theoretical and practical education. Perhaps the practitioners would be willing, or anxious, to register under the state laws and receive a license to practice. But why call it engineering?

A number of such titles have appeared in the past few years, Here are some: Economic, Advertising, Box, Electric Heating, Gear, Saw, Business, Sheet Metal, Compressor, Chain Store, Grinding, Distributing, Fire Protection, Turret Lathe, Material Handling, Trouble, Galvanizing, Lubricating, Filtration, Cost Production, Merchant, Magnetic, Clutch, Liquidating, Packing, Maintenance, Human, and Temperature. All of these were followed by "Engineer" or "Engineering." Some of these titles may be justified. Some seem grotesque without an explanation. Some are useless even as sales slogans, the object of their creation, as is evidenced by the fact that their authors have stopped advertising them. When "Temperature Engineer" was brought to the attention of one of the ladies during a spell of warm weather, it elicited the inquiry, "Can they tell us when cooler weather is coming?"

The contrast between the specifications of the Clothing Engineer as given in the aforesaid editorial and the specifications of the Mechanical Engineer as given in the editorial in Mechanical Engineering for May, 1924, is remarkable. Members will do well to turn to the May issue and read them again.

I once gave the definition that a profession is engineering only when a knowledge and use of the elements of mechanics, electricity, and mathematics are necessary for its successful practice. But this would admit some of the aforesaid engineers. Perhaps they should be admitted. How should a new branch of engineering be established? Should the first-rank institutions of instruction christen them or should that task be undertaken by the national engineering society from the members of which they are evolved? Is it proper or not for the technical journals to accept any kind of self-styled engineering in their advertising? Shall we resort to argument or ridicule to combat the practice? Or shall we not combat it? The composite answers to these questions from the individual orthodox engineers will furnish the facts upon which the advertising editor, the publicity seeker, and the public will base their judgment.

One can pertinently ask, "will the term 'Engineer' suffer the fate of disrepute into which the term 'Professor' has fallen?"

Frederick Franz.

New York, N. Y.

The Dominion Water Power Branch of the Department of the Interior of Canada has recently prepared an analysis of the use of water-power in Canada for industrial purposes. This deals with the annual coal equivalent of developed water power, the coal consumption and imports by provinces and the corresponding water-power resources and development, the strikingly smaller coal consumption per capita in Canada than in the United States, etc. Copies may be obtained from the Director of Water Power, Ottawa, Canada.

Engineering and Industrial Standardization

Recent Action by American Engineering Standards Committee of Interest to Mechanical Engineers

American Standard Screw Threads

THE first report of the Sectional Committee on the Standardization and Unification of Screw Threads has just received the approval of the American Engineering Standards Committee as an American Standard. It is in the form of a 32-page booklet and covers threads for bolts, machine screws, nuts, and commercially tapped holes. The committee, which has carried forward this work under the joint sponsorship of The American Society of Mechanical Engineers and the Society of Automotive Engineers, was organized in 1920, and includes in its membership many of the most distinguished experts on this important and difficult subject.

The report has been prepared in collaboration and agreement with the National Screw Thread Commission, which includes several members of the sectional committee, and in which the S.A.E. and the A.S.M.E. are the two civilian participating organizations. The present report is based upon the "Progress Report" of the Commission.

By the adoption of the report of this committee, the above-mentioned types of screw threads for the United States are narrowed down to, and standardized upon, two series to be known as "American Coarse Series" for general work, and "American Fine Series" for work in which a finer thread is desirable. The same form of thread is used in both.

The adoption of standard screw threads is perhaps the most important single advance in American industrial standardization, certainly in the mechanical industries, since screw threads are fundamental to design and manufacture in every field, and enter into almost every kind of manufactured product and machine. In shipbuilding, and the manufacture and repair of automobiles and farm implements, in bridge and building construction, and in fact in every one of the great industries on which our mechanical civilization is built up, the standardization of screw threads is a factor of paramount importance, and the confusion which would exist in the complex mechanical equipment of today, if the diversity of form and numbers of thread which prevailed fifty years ago were to return, would be almost inconceivable. Years ago the threading of a bolt or screw was left to the judgment of the individual mechanic who produced it. Interchangeability was neither expected nor possible. In the present specialization of industry, however, manufacture of such material upon a standard basis is a necessary development involving economies and conveniences of great importance in every direction.

The Coarse-Thread Series is the present "U. S. Standard" (or "Sellers") supplemented by the "A.S.M.E. Standard" below one-fourth inch, and the Fine-Thread Series is the "S.A.E. Standard" supplemented by the "A.S.M.E. Fine-Thread."

Different classes of fit ("loose," "free," "medium" and "close") are established with corresponding numerical tolerances to provide for unavoidable inaccuracies of workmanship under practical conditions. A standard screw-thread nomenclature and also a system of identification symbols for use in correspondence, drawings, and shop practice, are established.

Referring to international standardization, the foreword to the report states: ". . . .the Sectional Committee hopes that further steps may be taken by mutual concessions which will result in bringing together the Whitworth (British) and the American systems of threads so as to secure interchangeability in the English-speaking world. The Committee also looks forward to the time when, by conferences with the standardization associations of the countries using the metric system, agreements along similar lines for fits and tolerances for metric threads will be brought about." Copies of this report may be secured on application to The American Society of Mechanical Engineers at 45 cents per copy, with a reduction for orders in quantity.

Specifications for Brass Ingot Metal Solder and High Sheet Brass

THE American Engineering Standards Committee has approved as "Tentative American Standard" the following three specifications which had been submitted by the American Society for Testing Materials:

Specifications for Brass Ingot Metal, Graded and Ungraded, for Sand Castings (A.E.S.C. No. H 10–1924)

Specifications for Solder Metal (A.E.S.C. No. H 11–1924)

Specifications for High Sheet Brass (A.E.S.C. No. H 12–1924)

The first of these cover brass ingot metal for sand castings, known commercially as red and yellow brass ingot, made wholly or partly from scrap materials. Seven typical alloys are specified and are designated as grades Nos. 1 to 7, in accordance with their decreasing copper content.

The specifications for solder metal cover lead-tin alloys commonly known as soft solder. Two classes, A and B, are given, in each of which several compositions are specified covering the range of alloys commercially used, and designated as grades 0 to 4, in accordance with their decreasing tin content. For galvanized iron and zinc, only class A should be used.

Specifications for high sheet brass are general ones, covering material commonly used for drawing, forming, stamping, and bending.

The approval of these three sets of specifications as "Tentative American Standard" was recommended by a special committee under the chairmanship of R. W. E. Moore. This special committee still has under consideration four other A.S.T.M. specifications. These are for admiralty gun metal, brass forging rod, free-cutting brass rod for screw machines, and naval brass rods for structural purposes.

Specifications for Steel and Wrought-Iron Pipe

THE American Engineering Standards Committee announces the approval, as Tentative American Standards, of A.S.T.M. Specifications for Welded and Seamless Steel Pipe and Welded Wrought-Iron Pipe. The A.S.T.M. initiated work on specifications for steel pipe in 1915, and on wrought-iron pipe, in 1918. In 1921 the work was broadened to include seamless as well as welded pipe, and modified to bring them in accordance with the American Standard Pipe Thread. The action by the A.E.S.C. on approval was taken in accordance with the recommendation of a special committee under the chairmanship of Stanley G. Flagg, Jr., and containing representatives of the following organizations:

American Railway Association, Engineering Division
American Society of Civil Engineers
American Society of Mechanical Engineers
American Society of Refrigerating Engineers
American Society for Testing Materials
Association of American Steel Manufacturers
Atlantic Coast Shipbuilders Association
Electric Light and Power Group, A.E.S.C.
Gas Group, A.E.S.C.
Manufacturers Standardization Society of the Valve and Fittings Industry
National Association of Heating and Piping Contractors
National Tube Company
Panama Canal
Society of Naval Architects and Marine Engineers
U. S. Navy Department, Bureau of Construction & Repair
U. S. Navy Department, Bureau of Engineering.

Symbols for the Electrical Equipment of Buildings

A LIST of eighty-five (85) symbols for use in wiring diagrams for buildings has been approved by the American Engineering Standards Committee. These symbols are the work of a sectional committee under the joint sponsorship of the American Institute of Architects, the American Institute of Electrical Engineers, and the Association of Electragists, International.

The present standard is a revision and a considerable extension of the list first compiled by the National Electrical Contractors Association, in 1906.

MECHANICAL ENGINEERING

A Monthly Journal Containing a Review of Progress and Attainments in Mechanical Engineering and Related Fields, The Engineering Index (of current engineering literature), together with a Summary of the Activities, Papers and Proceedings of

The American Society of Mechanical Engineers

29 West 39th Street, New York

Fred R. Low, *President*

William H. Wiley, *Treasurer* Calvin W. Rice, *Secretary*

PUBLICATION COMMITTEE:

Alex G. Christie, *Chairman* O. G. Dale

John T. Wilkin Ralph E. Flanders

K. H. Condit

PUBLICATION STAFF:

C. E. Davies, *Managing Editor*

Frederick Lask, *Advertising Manager*

Contributions of interest to the profession are solicited. Communications should be addressed to the Editor.

More Engineering in Salvage

The prevention of material wastes and the utilization of waste material are two subjects which have been before the general public in one form or another for so long a time as to be almost in danger of being hackneyed. Yet notwithstanding this, it is a fact that altogether too little attention has thus far been paid to them, at least by the majority of manufacturing industries. Engineering skill of a high order is demanded in all phases of waste reduction, but few concerns have treated these matters in other than a more or less perfunctory manner, the prevention of waste due to defective design, workmanship, or material and the disposal of waste products at scrap value seeming to be considered respectively as satisfactory solutions of these problems.

Investigation, however, will show that in many industries, more especially those having diversified lines of manufacture, certain of the waste products (including surplus materials) commonly considered as unavoidable can be eliminated in whole or in part, or, if not, can be disposed of at better than the customary scrap values, or else can be used in the plant itself either "as is" or by first undergoing some simple modification.

In the disposal of waste products and surplus materials, if better than scrap values are to be secured it is usually a matter of intelligent and systematic search for suitable customers. This search may be carried on in several ways:

1 Through the lists of consumers of one's own finished products
2 Through the purchasing agent, who has many contacts of one kind and another
3 Through commission houses.

These last are, for some products, the easiest channels of disposal, but in order for their services to be more commonly made use of, the range of materials handled by them will require to be largely extended.

A point well worth bearing in mind in this connection is that if the waste products of one's own plant can be used by other concerns, it is very probable that the reverse of this is also true, and that the waste products of other concerns can in like manner be used in one's own plant to advantage.

For the benefit of those who may not yet have given the study to these matters of which they are deserving, and as an indication of the form and variety which such savings may take, a few random examples are herewith set forth:

1 Files, when they become dulled, instead of being scrapped as is too often the case, can be resharpened by means of a suitable sand blast and again used to excellent advantage, giving in most instances every bit as good service as new files.
2 Misprint or other defective salt bags can be purchased and used about a plant as carriers for small items, such as screw-machine parts, punchings, etc. They are cheap, capable of being used again and again, and for these reasons, together with that of permitting their contents to conform to any shape for temporary storage, are to be preferred to other types of containers.
3 Belting may be reclaimed in one's own plant, first cleaning it by immersion in gasoline, then cutting out and replacing worn portions. These worn portions may be used for a variety of purposes, such as hand leathers or washers, or they can sometimes be sold for the manufacture of boot heels, etc. There are also certain concerns who make a regular practice of reclaiming belting, and whose services may be enlisted for such work.
4 Used sugar bags, opened at the seams and washed, make the finest kind of wiping cloths for polished surfaces and are superior to cheesecloth or canton flannel because they are free from lint and in most cases cheaper.
5 Short drills may be turned into counterbores.
6 High-speed cutting tools, when too short for their purpose, can be lengthened by forging to the next smaller size, or the short ends can be welded to cheaper steel shanks and used in this manner.
7 Castings on which machine labor is being performed and in which defects appear, may sometimes be welded without removal from the machine, thus saving labor, material and time.
8 Short ends of wood may, at times, be disposed of to manufacturers of brushes for brush backs.
9 Sawdust makes an excellent material for packing purposes, as well as a good extinguisher for small oil fires.
10 Regular inspection of all air, water, and steam lines and of air hose, of tools for leaks, and lights left burning needlessly will invariably pay for itself.
11 Near-white and colored rags may be substituted for cotton waste and when soiled can be sent to laundries and washed and cleaned on the basis of a regular price per pound for all rags returned, or they may be reclaimed in one's own plant by means of a rag-cleaning equipment.
12 Sorted and baled waste, such as paper, rags, and sheet material, brings higher prices than when these articles are in loose form.
13 Self-closing faucets, especially for the hot water, will prove an economy in all plants.

The savings stated are largely made from the so-called expense materials, but similar savings may be effected in many plants from productive materials as well.

Since these vary, however, with each plant's products, it is manifestly impossible to set them forth in this article, and moreover they would not be of general interest.

To accomplish savings such as these would require the services of engineering talent having not only a wide knowledge of the more common wastes and their uses but a detailed knowledge of the wastes peculiar to individual plants.

The increasing need for the prevention and utilization of wastes of all kinds will gradually, in most large plants, force the development from among their staffs of reclamation engineers to cover such fields, while smaller plants will find it necessary to place their problems of this kind before consulting engineers, whose present fields may require enlargement to include such work.

C. B. Auel.[1]

[1] Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa. Mem. A.S.M.E.

Civil Aviation in Canada

THE Department of National Defense of the Dominion of Canada is giving active encouragement to civil aviation and has just published a report of civil aviation in Canada for 1923. Military and naval aviation is not included. There are fifteen firms which have operated aircraft, and in addition the Royal Canadian Air Force has done a great deal of non-military work. An important part of all of this work has been in connection with forest conservation. The Imperial Forestry Conference and other Dominion forestry bodies are urging the Dominion Government to enable this work to continue either by subsidies or by donation of Air Service facilities. Other activities which have been carried on are the transporting of passengers, advertising, exploration, reconnaissance, sketching, and photography for forestry, railway, and topographical purposes. In the course of this work flights covering 2830 hours have been made by civil planes and others covering 1422 hours by military planes engaged in civil work.

The Dominion Government has ratified the International Convention for Air Navigation and has representation on the International Commission. The United States has not participated in this Commission as yet. Owing to the nature of the country there has as yet been no development of mail or express service in Canada, but the Post Office Department is alive to the possibilities of such service in the future. The Dominion Government is to be congratulated on the encouragement being given to civil aviation.

Sanford A. Moss.[1]

Binary Vapor Prime Movers

THE fact that binary-vapor steam-mercury boilers have been sponsored by a corporation of the high standing of the General Electric Company has undoubtedly had the effect of encouraging others in pushing forward research on machinery working on similar principles. In fact, *The Scientific American* recently described an installation where water vapor was combined with that of another substance of a lower boiling point which might be something like carbon tetrachloride, the main material used in a number of fire extinguishers.

As a matter of fact the search for substitutes for steam, or binary-vapor systems, where other materials than water coöperate with steam, is apparently quite an old one, and attention may be called, in this connection, to a comprehensive paper[2] presented before The American Society of Mechanical Engineers under the title, Substitutes for Steam, by George H. Babcock as early as the year 1886.[2]

Even at that early date there was a multitude of such engines, the first use of other vapors than that of water for producing power being credited to Rev. Dr. Edmund Cartwright. In 1797 he patented an engine in which he proposed to use "ardent spirits of ether, or any other spirit more volatile than water, either wholly or in part." A reading of his specification would indicate that he had prophetic vision in other ways, as he also proposed to attach this engine to a still to utilize the vapor therefrom, first for power and afterward, when condensed, for sale or, possibly, home consumption.

The next idea was to vaporize alcohol by injecting it upon the surface of a highly heated fluid, such as oil, the pressure being transferred by the oil to a piston in a communicating cylinder.

As early as 1826 a London paper announced that three-quarters of the fuel then used in navigation would be saved by substituting the vapor of quicksilver for steam.

In 1842 du Trembley in France patented a true binary engine, using steam in an ordinary engine, condensing it on a surface in contact with liquid ether. This, at a temperature corresponding to, say, 15 in. vacuum in the condenser, produced a vapor having a pressure of about 50 lb. above atmospheric, which vapor was used to develop power in another cylinder and was itself condensed to as low a temperature as possible. As a matter of fact, no less than eight vessels were fitted with these engines. The process did not prove ultimately commercially successful, because several of the vessels came to grief from the dangerous character of the vapors which no care could confine.

We have then a long series of carbon-bisulphide engines for which great claims were made and which, one after another, disappeared into the limbo of forgetfulness, sometimes after a more or less disastrous explosion.

Another impractical principle was embodied in the Cloud engine of William Mount Storms. Here air was admitted to the cylinder before the steam port opened, it being claimed that the air was expanded by the heat received from the steam which greatly increased the pressure and effectiveness. Even before Mount Storms, however, one W. H. Hall, of Baltimore, patented a steam and gas engine in which the products of combustion from the chimney were to be pumped into the steam space of the boiler to add by their heat and expansive force to the economy of the engine. A somewhat similar idea was worked out in 1867 by an Englishman, George Warsop, who heated his air by the exhaust, then by the waste gases of the chimney, after which the air was mingled with the steam in the boiler. There is a certain amount of irony in the fact that the British Association, which, in its time, declined to publish a paper by Henry Bessemer describing his process of steel manufacture, did accept a paper on the Warsop engine claiming a saving of fuel of 47 per cent.

The fact that all of the engines referred to above failed to gain a foothold, even in competition with the steam engine of 30 or 40 years ago, inefficient as it then was, does not mean, of course, that the same principle might not prove successful today. There have been many instances when ideas have failed simply because an effort was made to apply them ahead of their time. James Watt, in one of his letters, states that the steam turbine will not be a serious competitor of the steam engine unless God makes machine parts move at a speed of 1000 ft. per min., and as a matter of fact, he was right, and the steam turbine did not become commercially successful until the machine-shop industry and metallurgy reached the stage of development where very high-speed machinery became available at reasonable prices.

Mr. Babcock, in the paper referred to above, describes, among other things, an engine built nearly 100 years ago by that wonderful mathematician, Sir George Cayley, who, by the way, established the laws of stability of aeroplanes four scores of years before the first aeroplane was flown. The principle of the Cayley machine is remarkably similar to that of the Humphrey gas pump and yet the former was a failure and the latter a success.

While, therefore, the fact that attempts to build binary engines failed in the past, does not mean that such engines cannot be successfully built today, it should be clearly borne in mind that the field of binary engines is by no means a virgin one but on the contrary has been plowed over pretty thoroughly. That, however, it has not been entirely exhausted is well illustrated by such recent developments as the Emmet steam-mercury boiler and turbine and the Scott-Still Diesel steam engine, where success has been attained by the development of contributory arts.

American Engineering Achievements to be Shown at Olympia Exhibition

MECHANICAL ENGINEERING is in receipt of a letter from F. W. Bridges, general manager of the Shipping, Engineering and Machinery Exhibition held annually at Olympia in London, in which he states that recent extensions of the exhibition building at Olympia will permit the devotion of a certain portion of the building to an American section. Mr. Bridges will be in the United States about the middle of October to consult with manufacturers of American machinery about the development of this American section of the Exhibition which will be held November 23 to December 5, 1925.

Engineering firms interested in export development may send inquiries to Mr. Bridges, care of the A.S.M.E., 29 West 39th Street, and they will be referred to him upon his arrival.

In his letter Mr. Bridges explains the relation of the American Section to the Olympia Show.

"During the past twenty years there has been held at various intervals in London a series of Shipping, Engineering and Machinery Exhibitions at which the manufacturers of all nations

[1] Engr., Mech. Research Dept., General Electric Co. Mem. A.S.M.E.
[2] *Trans.*, vol. 7, pp. 680–741.

have been represented, but although the largest exhibition building in England has always been secured it has been a matter of regret that the limitations of space have prevented adequate representation of America. This handicap, however, no longer exists, a 50 per cent extension of the exhibition building known as Olympia having been made recently which necessarily gives a very considerably increased area for the display of exhibits from other nations.

It has been arranged that the next Exhibition shall be held from November 23 to December 5, 1925, under the presidency of the Hon. Sir Charles A. Parsons. The President, Chairman and Members of the Honorary Committee of Exports will be delighted to have a thoroughly representative display of the latest and most approved specialties on the American market, and have therefore decided to devote a certain portion of the building to an American Section, which it is hoped may in every way eclipse the very fine Holland Section at the 1919 Exhibition."

Let the People Know[1]

MY THEME, is that the people at large are not told enough, and are not told in the right way, about what is being done for them by the laborers in research, invention and construction, the makers and the maintainers of the mechanical age.

Surely you will say mechanism is able to be its own prophet and speak for itself. The mighty works of the past hundred years are daily before our eyes. We are served by machinery from hour to hour. Everybody should be grateful and eager for more. But, in fact, there is no such popular satisfaction and renewed demand, and every fresh advance by applied science encounters resistance, not only from the multitude, but from what are usually described as vested interests. In the latter case it is Yesterday opposing the advent of To-morrow. In the case of the general public it is the Fifteenth Century trying to govern the Twentieth.

Coming to grips with my subject I perceive three points that demand argument: and I recognize that I am between two parties more or less indifferent to each other. I am trying to marry incompatibles; at any rate, in their present mood. My first question is whether it is of any benefit to engineering and applied science generally that the public should be sympathetic and hopefully inquisitive. My second is whether it is of any benefit to the public that science should endeavor to express itself in popular terms. And my third concerns the best ways and means of establishing permanent communications.

I would answer my first question by claiming that if once democracy became seized with the importance of accelerating mechanical progress, the endowments for which experimental science is always pleading would be bestowed in bounteous magnificence. What happens when public opinion is tuned to sing in chorus for some reform? Every political leader and every newspaper editor take prompt notice. Former speeches or past leading articles are not allowed to stand in the way. The people will get what they want, or at any rate what they are asking for. Why should they not be trained to demand full steam ahead and a clear road for the advancement of mechanical science?

"In other words, what we need is a popular vogue. We have to get rid of the conception of the man of pure science as a cranky recluse, and the man of applied science—the engineer and the chemist and the biologist—as either a sort of tame magician whose tricks are rarely amusing, or as a slavish tool of the mighty capitalist with nothing to bestow upon the populace. Is it necessary for me to argue further that to have an eager and sympathetic public opinion on their side would be a great score for the practical and progressive men who are daily making fresh conquests over obdurate nature, but whose campaign is hampered and retarded by the inertia or even the active opposition of the multitude, or of organized sections?"

As I am at this stage appealing plainly to intelligence I can see no possibility of two opinions on this question. Let us proceed to the next. What have the people at large to gain by being kept informed regularly and artfully—using the word in its true and best sense—of the advancement of science and of its direct advantage to all mankind?

[1] Abstracted from an address by T. C. Elder before the First World Power Conference, London, England, July 9, 1924.

Here the reader may be surprised to be told that there is any difficulty of demonstration, assuming that reader to be, say, an electrical engineer or an industrial chemist. But I can assure him that there is a widespread impression that the ordinary man and his family gain nothing from his work. Actually in the House of Commons within a year or so from today one of the leaders of the Labor party, eminent among its so-called intelligentsia, delivered a speech in the House of Commons all in this strain. The working man, that hackneyed political figment which always defies definition, was pictured as a creature working painfully amongst mighty machines merely to make profits for shareholders and never himself gaining any benefits from the tidal wave of invention that has swept over civilization during the past hundred years.

What was more astonishing to me than this preposterous assertion was the unquestioning acceptance of its essential truth by a leading journal devoted to engineering, which in its editorial comments inquired most sympathetically how this deplorable failure of mechanism could be retrieved.

It is not for the sake of scoring off any poor ignorant politician that I adduce this instructive example, and therefore I use no names. But speaking mainly to engineers, am I not proving my case that it would be far better for them and for the community, if the people understood better that, in Britain, for instance, in the first place, they could not live at all in such dense numbers without the constant daily and hourly service of engineering, chemistry and biology; in the second place, that they get in addition to that bare existence many comforts and luxuries which familiarity has made commonplace, but which would have seemed miraculous to our grandfathers; and in the third place, that they will as a community suffer a fearful disaster if the flow of this brain work for their benefit is not merely maintained at the same volume but progressively increased?

There is not one person in a thousand I suppose, who would immediately assent to these propositions. So that you have as a background to the World Power Conference a huge majority of the people, with political life and death in their decision, in this very dangerous condition of ignorance. Their ear is always for the man who promises paradise by act of Parliament; never for the man who knows how to effect gradual improvement by the better organization of natural forces. In politics—now everybody's business—the engineer and his like have not the slightest influence and receive not the smallest respect.

Is not this astonishingly wrong in what we flatter with the name of Mechanical Age?

The ways in which, if these thoughts seem reasonably convincing, the men of applied science should attempt to get public opinion solidly favorable behind them, are largely those adopted by other causes.

Where you find millions of people daily is opposite a newspaper or a cinema screen. There is room both on what is affectionately called the "silver sheet" and in the newsprint column for more messages from science to the public, as I can certify from personal experience in both cases. The messages, however, should aim at being suggestive rather than informative. In balancing those two words I am challenging a great body of opinion which includes eminent publicity men and propagandists. I have, however, no doubts on this question, and my assurance is based on long observation of causes and effects in social and political and industrial movements, and on the study of modern psychological theories. Much of the practice of publicity conflicts in my judgment with principles that are only now beginning to be established.

I cannot regard the discussion of ways and means in detail as an essential part of this paper, because it can only be justly treated in much larger space than is permitted. Nor can I make any positive recommendations for giving practical attention to this public need which I have endeavored to sell to engineers and their colleagues in applied science; beyond the single downright assertion that no learned institution of any kind is properly fulfilling its whole purpose in these democratic times if it possesses no plans whatever for *letting the people know* what its work means for the furtherance of civilization in the interests of all.

We have heard so much in this generation of the Right to Live and the Right to Work, principles that are faintly perceptible in the political mist. Much social perplexity could be relieved by a popular insistence upon the Right to Know.

Fourth New Haven Machine-Tool Exhibition

THE fourth New Haven Machine-Tool Exhibition opened at 10 A.M. on Monday, September 15, at the Mason Laboratory, Sheffield Scientific School, New Haven, Conn. and continued through four days. There were over 125 exhibits in the Laboratory and the visitors on the opening day were enthusiastic about the novelty and diversity of the showings. The Exhibition was held under the joint auspices of the New Haven Section of the A.S.M.E., Yale University, and the New Haven Chamber of Commerce.

The Machine Shop Practice Division of the A.S.M.E. coöperated with the Exhibition Committee in the provision of a technical program with sessions on Tuesday, Wednesday and Thursday.

The following is the program:

Tuesday, September 16, 3:30 p.m.

J. A. Smith, *Chairman*, Machine-Shop Practice Div., A.S.M.E., Gen. Elec. Co., Schenectady, N. Y., presiding.

Review of Foreign Progress in Research in Machine Shop Practice, by C. A. Beckett, New York.

Discussion on Research in Machine-Shop Practice in the United States, by Wilfred Lewis, Philadelphia, Pa., B. H. Blood, Hartford, Conn., and others.

Forecasting Demand for Machine Tools, by E. F. DuBrul, Gen. Mgr., National Machine Tool Builders Assoc., Cincinnati, Ohio.

Tuesday, September 16, 8:30 p.m.

Dr. Ira N. Hollis, Worcester, presiding.

General Discussion of Education and Training for the Industries, by J. A. Smith, Gen. Elec. Co., Schenectady.

Wednesday, September 17, 3:30 p.m.

Comparative Methods of Tool Design and Relation to the Quantity Production of Sheet-Metal Parts, by D. M. Chason, Elizabethport, N. J.

Application of Ball Bearings to Machine Tools, by H. Reynolds, New Britain, Conn.

Shop Measurements, by Earle Buckingham, Hartford, Conn.

Thursday, September 18, 3:30 p.m.

Selling Standards to Manufacturing Organizations, by E. C. Peck, Cleveland, Ohio.

Standardization versus Individuality, by L. D. Burlingame, Providence, R. I.

The Value of Standardization with Examples of Accomplishment, by Geo. T. Trundle, Jr., Cleveland, Ohio.

Manufacturing Design of Ordnance Material, by J. D. Pedersen, Springfield Armory.

The papers by Messrs. DuBrul, Chason and Buckingham appeared in the September issue of Mechanical Engineering. Mr. Beckett's paper is included in this issue. The November issue will contain a record of the discussion at the meeting.

Opening Session

Dean Harry S. Graves of the School of Forestry and Provost of Yale University was introduced as presiding officer of the opening session by H. R. Westcott, chairman of the Exhibition Committee. Dean Graves welcomed the visitors and pointed out the significance of the enterprise as an opportunity for scientists and practical men to come together in the service of industry. Dr. George K. Burgess, Director of the U. S. Bureau of Standards, delivered an address, an abridgment of which follows:

The Government and the Machine-Tool Industry

The machine-tool industry is one of the great industries of the country. It is largely the outcome of American initiative, engineering skill and inventive genius. It may also be called one of the most important of our key industries, for upon its development and healthy condition depend in large part the progress and economical output of several other of our largest manufacturing industries such as the automotive, agricultural-machinery and electrical-equipment industries, and especially in time of war, the production of ordnance material.

Closely related to the development and use of machine tools, are two other great American contributions to the progress of industry, one economic and social, the other metallurgical. Both are largely the product of one man, Taylor. I refer to what is commonly called the Taylor system of planning and executing work. These three related factors, machine tools, the Taylor system, and improved materials for cutting tools, have progressed side by side, and have given its preëminent position to the American metal-product and machinery industry. Perhaps the outstanding characteristics of the machine tool are adequacy of design for the purpose, long life under severe usage, simplicity and speed of operation, and accuracy or identity of product within well defined and often extraordinarily close tolerances. All of these characteristics are constantly being studied with a view to their improvement, by manufacturers, engineers, and technical committees, both in shop, laboratory and around the council table.

From a Government representative, you will perhaps expect a statement of the Federal agencies interesting themselves in the machine-tool industry, what they do and how it is done.

Size of the Industry

Let us first briefly picture the size and extent of the industry as shown in Government reports largely compiled of course from data furnished by the manufacturers and exporters.

During the war and the post-war period the production of machine tools was abnormally high, shipments reaching 165 per cent of the 1913 period followed by an abrupt depression to 20 per cent in 1921 from which the industry began to recover in 1923 but reaching only 44 per cent of the 1913 business. The value of production of machine tools and other metal-working machinery in 1919 was $269,941,000, and in 1921 it was but $88,542,000, the exports falling off proportionally by 68 per cent or remaining at 22 per cent of the total. The number of establishments decreased from 614 in 1919 to 174 in 1921. It is also of interest to note that for the five years preceding the war Germany was our best customer for metal-working machinery taking over two and one-quarter millions of dollars' worth.

Governmental Activities

Turning now to the Governmental activities, the Department of Commerce has three great service Bureaus, Census, Foreign and Domestic Commerce, and Standards, which are particularly close to industry, the first concerning itself with statistics, the second with business, the third with science and technology. There is also the Division of Simplified Practice, whose function it is to assist industry in reducing types, varieties and styles of manufactured products. The Bureau of Standards, in addition to its work of testing and experimental research, is also acting often in association with other bodies, such as the American Engineering Standards Committee and the American Society for Testing Materials, in formulating specifications for materials, performance of machines and instruments, and preparing standards of practice and safety codes.

The War and Navy Departments have, in the Arsenals and Navy Yards, great manufacturing establishments which are vitally interested in machine tools and their accessories, such as gages and in many problems relating to standardization. The Ordnance Department of the Army, for example, has some 1200 items or standard articles, 75 per cent of which are manufactured with machine tools and also owns many screw machines. As to gages, this department has now stored about one-half million having a value of $35,000,000.

The Federal Government, in the Federal Specifications Board, now possesses a centralized representative body responsible for formulating and promulgating specifications for all commodities purchased by the government.

Congress in 1918 created a body of the greatest import to the machine-tool industry, the National Screw Thread Commission, composed of representatives of the Departments of War, Navy and Commerce and of The American Society of Mechanical Engineers and the American Automotive Society. This Commission, is about to issue its second report.

Several of the Government Departments are represented on the American Engineering Standards Committee, a national organization founded by the engineering societies and supported by them and by contributions from industrial concerns. This body has underway in its sectional committees numerous standardization projects relating to mechanical engineering and metal products. One of the most active of these sectional committees is concerned with the standardization of Plain Limit Gages for General Engineering Work, which with its subcommittees on Methods of Gaging and on Limits, Manufacture and Use of Gages is meeting in New Haven during the Exhibition period.

Problems at the Bureau of Standards

[Doctor Burgess discussed the relation between the United States yard and the meter, and the temperature at which measurements are standardized. These were taken up at length by Mr. Buckingham in his paper on Shop Measurements which appeared in the September issue of MECHANICAL ENGINEERING. Doctor Burgess recommended that 68 deg. fahr. be adopted as the standard temperature for measurements and that a new definition of the yard and the meter be made in terms of light waves to remove the present lack of understanding as to the inter-relation between these two units.—EDITOR.]

Mention may be made of the work being done by the Bureau of Standards along the general lines of dimensional standardization and in the field of precision screws and gages.

In coöperation with the National Screw Thread Commission and the various Sectional Committees organized under the American Engineering Standards Committee, the Bureau is taking an active part in work of this character.

Screw-thread standards have been established covering a coarse and a fine-thread series of bolts and nuts; threads of special diameters, pitches, and lengths of engagement; fire-hose threads; and pipe threads. Standard dimensions and tolerances for a complete line of threading tools and gages as well as for the product, have also been adopted and will be included in the 1924 revision of the Commission's report, which has just been submitted for approval of the Secretaries of War, Navy, and Commerce, and is now ready for the printer.

The 1921 Progress Report was widely accepted in the industries, and it is believed that the 1924 Report, which has been rearranged and enlarged, but not changed in any essential features, will be found still more valuable and convenient.

The work of the Plain Gage Committee, with which the Bureau is coöperating, has also made good progress. The Committee has agreed upon a classification of machine fits, including allowances and tolerances for each class, and upon a classification of and specifications for plain limit gages for general engineering work. The report, which has been approved by the Committee, is based upon the manufacturing experience of many prominent engineers and manufacturers of interchangeable parts, and should serve as a very helpful guide in this field.

Precision Screws and Gages

The Bureau's work on the production of precision screws has been the outgrowth of demands from manufacturers of dividing engines and similar apparatus for screws of high accuracy. The production of screws of this character involves many problems which the commercial manufacturer is not ordinarily in position to solve. Many of the problems involved in cutting, grinding, lapping, and mounting precision screws for use in producing other screws, and for the operation of dividing engines and similar apparatus, have been successfully attacked and their solution has made possible the production of screws of higher accuracy than previously attained. This work is being continued and it is confidently expected that within a relatively short time, possibly within the next year, the Bureau will be able to meet the most exacting demands of industry and science in this important field.

By methods developed at the Bureau precision gage blocks of high quality are now produced commercially in the United States, whereas previously they were available only by importation. There is no longer the danger of the price's becoming prohibitive as the result of unusual commands, or of the supply's being cut off in time of war.

The laboratories of the Bureau are equipped for carrying out investigations and tests of gages, measuring tools, graduated scales, and other apparatus and measurements, such as coefficients of expansion, of importance to the builders of machine tools and I should welcome the opportunity of placing these facilities at your disposal, and of rendering all possible assistance in the solution of your problems.

Metallurgical Items

Some of the metallurgical items in which the Bureau is coöperating with the machine-tool industries may be illustrated by researches relating to the heat treatment and performance of high-speed lathe tools and the study of steels for gages. The work on high-speed steels is being carried out jointly with the metallurgical staff of the Washington Navy Yard but has had the active coöperation of steel manufacturers and others. It originally consisted of a critical survey of so-called competitive break-down tests used by large consumers as the basis of purchase of high-speed steels. Subsequently a study was made of the heat treatment of several important commercial types in this group of steels and at the present time attention is being given to tool performance in rough turning, different carbon and alloy steels first heat treated in various ways.

So far, important limitations have been developed in both the "Breakdown" and "Taylor tests" and much data obtained concerning heat treatments giving longest tool life under severe service and the prevention and elimination of the undesirable conditions concomitant with "flaky fractures" sometimes developed in the treatment of high-speed steels.

The work with gage steels is being carried out under the direction of a special committee composed of gage makers and users, steel manufacturers and representatives of various government departments; it requires and has the active coöperation of all interests represented and its ultimate purpose is the preparation of specifications covering the composition and heat treatment of steels better suited for gages than those now most generally used. So far material progress has been made in the study of some of the principal variables to be considered such as wear resistance, control of dimensional changes in hardening and subsequent time changes. Wherever possible, laboratory experiments are supplemented by service tests and there are at present in various plants or in preparation for such service tests more than one hundred gages a complete history of which is available.

There are of course many other metallurgical researches in progress of particular interest to the machine-tool industries. In this group may be mentioned the investigation of quenching media for heat treatment especially in relation to the hardening of carbon steels; the investigation of the effect of quality of steel upon the results obtained in case-hardening, which because of the nature of the variables encountered, brings to mind the extensive work carried out during the past few years relating to gases in metals.

Division of Simplified Practice

As to simplification, the elimination of sizes and varieties which can advantageously be dispensed with, the Division of Simplified Practice has the following program relating to matters of interest to the machine-tool industry.

Simplified Practice Committees have been making intensive surveys in four of the following fields, and have rendered occasional reports of progress to us:

1 *Milling Cutters.* Up to date, a simplification program involving a 30 per cent elimination of varieties has been drafted, and a general conference on this subject is imminent.

2 *Taps and Dies.* A survey is in active progress and it is thought by the Simplified Practice Committee that a 32 per cent elimination of varieties may be eventually practicable.

3 *Lock Washer and Nut Lock Manufacture.* Within the Simplified Practice Committee there is not a unanimity of opinion as to just which eliminations would be practicable, for the reason that this project is interdependent upon standardization in allied fields. However, the Committee concurs in the belief that eventually definite eliminations in diameters and thicknesses will result in cutting off approximately one-third of the present list.

4 *Drills and Reamers.* An eventual elimination at least of 15 per cent is contemplated by the Simplified Practice Committee.

5 *Arbors for Drill Chucks.* There is no trade association through which we can work, and our contacts have had to be made through correspondence with scattered individual firms. Some interest has been manifested, but not sufficient to warrant the institution of concerted action.

6 *Carriage and Machine Bolts.* Recommended, prepared and accepted, but is now in the hands of a special committee for modification, this project being dependent upon wrench-opening standardization.

7 *Expansion Lathe Mandrels.* The Navy Department points out the need for simplification in this field. We are now making a study of the situation.

Considering machine tools as "The Master Tools of Industry" (the slogan for which Dean Kimball of Cornell recently won a $500 prize) I believe that an increased demand for such tools will arise out of the continuing simplification of commodities. For example, as paving bricks are simplified to a common size, brick-laying machines will be more practicable, and the increasing use of those machines will require more machine tools to make them.

Similarly, simplifying containers, etc., to standard sizes permits mechanical handling and increases demand for conveying, packing, and wrapping machinery, and thus increases demand for machine tools to build these "special-purpose" machines.

Also, the restriction of immigration, and consequent shortage of common labor intensifies the need for labor-saving machinery, and the consequent demand for the "master tools" which make them.

Federal Specifications Boards

I cannot close without further reference to the Federal Specifications Board. When it is recalled that the Federal Government is the largest buyer in the country purchasing some $260,000,000 worth of commodities a year, the importance of a Federal policy relating to purchases and unified specifications becomes apparent.

By direction of the President, there were established several coordinating boards relating to certain specific activities of the Government. The Federal Specifications Board is the only one of interest to us for the moment.

Up to the present time, 210 master specifications have been promulgated as official Government standards. Some of these specifications are of particular interest to machine-tool manufacturers; for example, lubricants; belting; various paint and varnish materials; soap; fire extinguishers; hose; electrical supplies; bituminous materials; packing and gaskets; metals; etc.

The Board now has under consideration, specifications for abrasives and polishing materials, hack saws, tool steel, and will probably soon take up the consideration of gages. A complete list of the specifications, and instructions for their procurement, can be obtained by addressing the Federal Specifications Board, care of the Bureau of Standards, Washington, D. C.

Great strides have been made in the art of machine-tool production in the last generation, and in that production there is a large gap between the inception of the original idea and the consumer; that gap has been filled with the efforts of the inventor, engineer, physicist, chemist, business man and economist.

The standardization of machine-tool elements and small tools offers a fertile field for great contributions to national prosperity and economy. This general problem has much in common with all other problems of standardization. The elimination of unnecessary sizes would be of primary importance. The standardization of work-holding and tool-holding devices now under way will be of almost equal importance.

Educate the Sons of Mary

ELSEWHERE in this issue we print an abstract of an eloquent address entitled Let the People Know, urging better and more complete publicity for scientific and engineering work. In this connection we call attention to a remarkable little book, Popular Research Narratives, reviewed in the August issue of Mechanical Engineering, and published by Williams & Wilkins Co., Baltimore, Md., for the Engineering Foundation. The book has gone not only over the United States, but to Europe, Africa and Asia in its mission to the Sons of Mary. From these fifty tales of research and invention, the engineer as well as the layman, will gain a more complete realization of his debt to science.

Changes in Admission Requirements Affect Columbia Engineering Students

IT IS now possible for an engineering student at Columbia University to obtain his degree in five years instead of six. Changes have recently been announced by Dean George B. Pegram of the School of Mines, Engineering and Chemistry, which add flexibility to the admission requirements but do not modify the three-year professional engineering course. Since 1914 the Columbia engineering schools have required for admission not less than three years of undergraduate collegiate study. The Columbia authorities have approved a modification of the admission requirements under which a student entering Columbia with credits in elementary physics, chemistry, and advanced mathematics may on completion of a prescribed course covering only two years and a summer session, be admitted to the Schools of Mines, Engineering and Chemistry. These changes do not affect in any manner the three-year professional engineering courses.

Franklin Institute Centenary

THE centenary of the Franklin Institute which included the inauguration of the Bartol Research Foundation was celebrated in Philadelphia, June 17 to 19, 1924. A large gathering of members of the Institute and of representatives of institutions of learning, technical societies and industrial organizations, both American and foreign, participated in the sessions which were addressed by engineers and scientists of international fame.

Franklin Institute has completed a century of useful effort in stimulating scientific research and it is fitting, therefore, that the celebration of this centenary should also mark the inauguration of the Bartol Research Foundation with its fund of more than one million dollars as a powerful instrument to secure advances in the fundamental questions of physical science.

Dr. Elihu Thomson, Honorary Chairman of the Celebration Committee, presented the first formal address which was an inspiring narrative of the achievements of the Franklin Institute and its contribution to knowledge and human well-being. Dr. Thomson emphasized the fact which is often forgotten when discussing modern weapons of destruction, which science has made possible, that science is also the great instrumentality for the establishment of peace.

An open meeting was held Thursday evening, September 18, with an address by Sir Ernest Rutherford on the Natural and Artificial Disintegration of Elements. The inauguration of the Bartol Research Foundation took place on Friday morning, September 19. Dr. Arthur D. Little delivered an address defining the Fifth Estate, as "that small company upon whose creative effort the world depends for the advancement of science." He declares that the knowledge, vision and open mind possessed by members of the fifth estate should be brought to bear in the formulation of national policies and the solution of govermental problems. The Stimulation of Research and Invention was discussed by Dr. D. S. Jacobus. Dr. Jacobus' address appears as the leading article in this issue of Mechanical Engineering. At a banquet on Friday evening, greetings from universities, colleges, learned and professional societies and industrial organizations were presented.

Twelve sectional meetings were held throughout the three days of the gathering and among the subjects of interest to engineers were: The Progress and Promise of Engineering by Dean Dexter S. Kimball; Recent Developments in Aeronautics, Prof. Jos. S. Ames; Military Aircraft and Their Use in Warfare, Major General Mason M. Patrick; Photo-Elasticity, Prof. E. G. Coker; Some Aspects of High Pressure Research, Dr. P. W. Bridgman; The Phonodeik, Dr. Dayton C. Miller; the Field of Research in Industrial Institutions, E. W. Rice, Jr.; Steam Turbines on Land and Sea, Sir Charles Algernon Parsons; Mercury Boiler, Wm. LeRoy Emmet; Modern Ordnance, Major General C. C. Williams.

The official representatives of The American Society of Mechanical Engineers were Pres. Fred R. Low and Past-President Fred J. Miller.

Engineers Urged for Federal Tax Board

A NEW possibility for public service on the part of engineers is indicated by the efforts to have members of the profession chosen by the Government to help settle Federal tax appeals. The scope of these endeavors, typical of editorial suggestions in various newspapers, is indicated in a resolution adopted by the Atlanta Chamber of Commerce, urging that of the remaining 16 members to be appointed to the United States Board of Tax Appeals, a proportional representation be accorded capable business men, including certified public accountants and consulting engineers and that the President and his advisers carefully make selection of such as are qualified by their experience, education and ability.

New Plan for Distribution of Papers at Coming Annual Meeting

WITH the growing size of the Society, the distribution of papers to the members previous to the meeting has been a serious problem. For the coming Annual Meeting which will be held in New York, December 1 through 4, a new plan will be put into effect which will give every member an opportunity to study carefully all the papers that have been printed previous to the meeting. The Committee on Meetings and Program has thoroughly appreciated the value of well-considered discussion as an important factor in the success of the Society meetings. Furthermore, the record of the papers in the Society's publications is greatly improved by critical or amplifying discussion with suitable closing remarks by the author. Therefore the Committee on Meetings and Program and the Committee on Publication and Papers are coöperating in this new plan with a view to increasing the value and interest of the meetings and of the published record.

The Plan in Brief

Briefly, the plan is as follows: The papers will be printed in two forms, the 6 × 9 size used for Transactions and the 9 × 12 size used for Mechanical Engineering. Synopses of all the papers printed in the 6 × 9 size will appear in the November issue of Mechanical Engineering and members may request copies of these from the office of the Society on a suitable form that will be provided for the purpose. The papers printed in the 9 × 12 size will be included in a special Mid-November issue of Mechanical Engineering which will be mailed to the membership on November 15 and should reach the most remote point in the United States by November 20, ten days before the meeting. Copies of the 6 × 9 papers will be available on request at the headquarters during the meeting but as the special issue of Mechanical Engineering containing the 9 × 12 papers will be sent to each member additional copies will not be issued at the meeting. There will be a limited number available for sale to those who do not care to bring the special issue with them.

Full announcement of this plan will also be made in the *A.S.M.E. News* previous to the meeting with forms for ordering the 6×9 papers.

Technical Program Promises Well

The technical program for the Annual Meeting gives promise of a great wealth of important material. The Machine Shop Practice Division will participate in several sessions: The first in coöperation with the Special Research Committee on Cutting and Forming Metals which will discuss various methods of measuring hardness; the second, with the Special Research Committee on Lubrication at which there will be several papers giving results of recent researches in high-pressure lubrication; the third, with the Management Division in a session devoted to production control; and the fourth, a General Session to consider mechanical springs, inaccuracies in gear teeth, and other design problems.

As usual, there will also be several sessions devoted to consideration of the important discussions of power problems, the Power Division sponsoring a session on steam power with papers dealing with boiler water conditioning, resuperheating in steam turbines, pulverized fuel, and the burning of small sizes of anthracite. This Division will also coöperate with the Fuels Division in a session on oil burning at which papers on marine practice, industrial practice, and the hazards of oil burning will be presented. A session on hydraulic power, also sponsored by the Power Division, will take up penstock and draft-tube design.

The Oil and Gas Power Division is planning a session with papers on the gas turbine and the solid-injection engine.

The Materials Handling and Petroleum Divisions have announced a session on handling and storing oil which will be a further valuable complement to the session on oil burning and on oil and gas power.

The Management Division is planning two sessions to be held jointly with the Taylor Society and the Machine-Shop Practice Division. At the first, Taylor's classic paper on Shop Management will be presented for discussion in the light of 21 years of experience with the methods suggested in the paper. The second session will be devoted to production control and methods of planning.

The Railroad Division will discuss the problems of turbine locomotives with papers giving the results of foreign experiences with this new type of motive power.

The newly formed National Defense Division will present a group of papers dealing with the elements of ordnance design and the inspection of materials.

The Aeronautical Division will treat of helicopters, aerial surveying, and metal-airplane construction.

There will be a joint session on mechanical design for safety under the auspices of the A.S.M.E. Committee on Safety Codes and the American Society of Safety Engineers which will take up pulverized fuel hazards and the development of intensive safety programs.

The Textile Division plans a discussion of the historical development of spinning and twisting and a paper dealing with the engineer in the field of cost control.

The Forest Products Division plans to discuss the fundamental power and material-handling problems of the lumber industry.

In addition there are a large number of miscellaneous papers available from which strong general sessions will be arranged.

Third Power Exposition

As usual, the National Exposition of Power and Mechanical Engineering will be held in the Grand Central Palace from December 1 through December 6, parallel to the meeting. The coming show is the third in the series and at the present time over 270 concerns have contracted for space.

The Air Mail Test

DURING July the New York–San Francisco Air Mail Service was subjected to a 31-day test. In the report of this test Paul Henderson, Second Assistant Postmaster General, reported a high degree of performance in the face of especially unfavorable weather conditions for night flying. The receipts from the sale of the air-mail stamps were much less than the cost of the service during this period but Mr. Henderson believes the matter of revenue should not be considered until the service has had a chance to justify itself and build up traffic.

During the 31 days of July, air-mail planes flew 173,910 miles. Over that part of the route operated at night, the weather was unusually bad. During the first 20 nights there were only six with clear weather straight through from Chicago to Cheyenne. The remaining 14 nights were cloudy, hazy, rainy and windy. There were frequent local storms amounting in certain instances to cloudbursts and tornadoes, and many electrical storms. Weather conditions such as these are an even greater menace to aviation than more severe rain and snow storms experienced in other seasons of the year. The very fact that these storms come up quickly and that they are severe while they last creates an unusual hazard.

Notwithstanding these storms the air mail was able to maintain an average of 39 hr. and 49 min. westbound, and 36 hr. and 21 min. eastbound, compared with the scheduled time of 34 hr. 45 min. westbound, and 31 hr. and 35 min. eastbound.

It is of interest to compare these averages with the best established rail schedules of 86 hr. westbound and 90 hr. eastbound. The poorest performance westbound was made on July 18, when 55 hr. and 40 min. were consumed. As compared to the best combination of rail schedules, this shows a saving of 30 hr. and 20 min. The poorest record eastbound was made on July 12, when 57 hr. and 39 min. were consumed. This, as compared to the best rail schedule eastbound, 90 hr., shows a saving of 32 hr. and 21 min.

Part of the delay during July was brought about by the fact that as yet there is no lighted air way into San Francisco, or New York. The lighted air way now extends only from Cleveland, Ohio, west to Rock Springs, Wyo. This resulted in delays overnight just a few miles outside of San Francisco and New York. The course from Mather Field, in the Sacramento Valley, to San Francisco is now being lighted; also the route across New Jersey into New York, so that ships arriving near New York or San Francisco early in the evening may proceed with proper lights to guide them. This should improve future performance. (*Aviation*, vol. 17, no. 10, Sept. 8, 1924, p. 964.)

Library Notes and Book Reviews

THE Library is a coöperative activity of the A.S.C.E., the A.I.M.E., the A.S.M.E. and the A.I.E.E. It is administered by the United Engineering Society as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West 39th St., New York, N. Y. In order to place its resources at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies of translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The Humanizing of Knowledge

THE HUMANIZING OF KNOWLEDGE. By James Harvey Robinson. Geo. H. Doran Co., New York, 1924. Cloth, 5 × 7½ in., 119 pp., $1.50.

TO THOSE of us who live, move and have our being in the fields of pure and applied science, and who have been reared to believe that the great hope of humanity lies in the scientific method of thinking, it is sometimes painful to reflect that millions of people in this country and elsewhere are not only ignorant of this method of thought, but have also little or no faith in its ultimate accomplishments. When Mr. Bryan rails at the theory of evolution we are amazed and cannot quite understand how a man of such apparent intelligence can doubt the evidence that, to the scientific mind, is so convincing. And we are prone to dismiss the entire matter by classifying Mr. Bryan and his kind with the ignorant, or at least with those whose fundamental education has been neglected.

In this little book the talented author of The Mind in the Making has endeavored to set forth some of the basic reasons for this lack of knowledge and distrust of science and scientific conclusions and to indicate some means of bettering this state of affairs.

He treats first of the reasons for mankind's general indifference to scientific truth and of the modern scientific movement that has so changed, for some of us, our conceptions of the relations of man to the universe. He then discusses, at some length, the organized opposition to these scientific views of man's place in the universe and the natural opposition presented by inherited tradition and belief, or "lore" as he calls it, to the scientific attitude of mind.

In the two last chapters entitled, respectively, The Problem of Humanizing Knowledge and How is Scientific Knowledge to be Democratized, the author puts forward the idea that the solution lies in making science or knowledge, which is really all that science is, more accessible to all men and women. This is, of course, not a new idea, but when presented against the background of the first part of the book it certainly takes on added strength and the author's reasoning is clear and concise.

There can be no compromise in this matter. The scientific method is true or false. If it is true, the only hope is to apply it to all problems, industrial, social, political and legal. We cannot make progress with part of the world using clear-cut logical methods and a larger part totally ignorant of these methods, resting their faith on tradition and speculative philosophy, denying the accuracy of the scientific method and closing their mind to honest conviction as to the truth of scientific evidence. To deny the accuracy of scientific reasoning is to deny the idea of progress itself. Scientists and engineers, at least, are not willing to admit such a possibility.

The author, therefore, makes a plea for the production, by scientists, of literature that will make their fields of study at least intelligible to the man on the street. He notes that the scientist usually writes for his coworkers and uses a vocabulary that is understood by them alone, the fear of ridicule by his coworkers often preventing him from "popularizing" his writings. Any one well acquainted with any branch of pure or applied science will agree that writings of a highly scientific character and in the scientific "jargon" of that field are, and will continue to be, a necessary part of progress in that field. But there is no reason why there should not be such books as the author describes that will state in simple English the great underlying principles and ideas on which these great fields of scientific thought are based.

As a matter of fact, a great deal of work is now being done in this direction and if the writer would offer any criticism of the book it is that it does not ackowledge this rapidly growing work. The large majority of our best lower-grade schools and high schools require training of all children in the fundamentals of such elementary sciences as biology, chemistry and physics. The tendency in all colleges of liberal arts is to require a minimum amount of study in science as a requisite for a degree. But most important of all is the very large amount of dissemination of elementary scientific knowledge that is now being carried on by the extension departments of our great universities, particularly the land-grant colleges. Perhaps no field of industry in this country has been brought so close to the scientific method as that most ancient calling—agriculture.

These remarks apply, of course, to conditions in America and a limited number of other countries. We are apparently gaining ground and there is hope that this spreading of basic scientific knowledge may grow apace. A less hopeful view must be taken of other lands and the work in prospect is vast.

This little book, therefore, will repay reading for it presents the case for science and scientific applications clearly and well. It contains much that is thought-provoking and stimulating. Lastly, it has the great merit of being a small book, the author like a true scientist saying what he has to say clearly, concisely and in as few words as possible.

DEXTER S. KIMBALL.[1]

Representative Government in Industry

REPRESENTATIVE GOVERNMENT IN INDUSTRY. By James Myers. Geo. H. Doran Co., New York, 1924. Cloth, 5 × 8 in., 250 pp., illus., $2.00.

MR. MYERS' book is addressed to the personnel of a bleachery, and the examples which he cites have to do almost wholly with the textile mills, where it is fair to assume the conditions are not closely analogous to those of machine-tool-building and other metal-working establishments.

To one without experience, it would almost seem from reading the first chapters of the book as if nothing good or honorable had ever come from the owners or managers of industry, and that it would be unreasonable ever to expect anything of the kind; and that the only possible way of avoiding bloody revolution would be to turn the management of industry over to the workers. It seems to have been forgotten that almost all of the owners and managers of industry have thus far been recruited from the ranks of the workers, and their decisions are not materially different from many of those made by committees under industrial management after they have acquired an insight into management.

Whatever justification there may be for the assertions made that there is extreme discontent in textile mills, it is hardly to be believed that these hold to anything like the same degree in engineering-manufacturing establishments, where the greater variety of work and the installation of moving or task-performing machinery and equipment may possibly stimulate the interest of the producers more than would be the case with a piece of cloth.

[1] Dean, College of Engineering, Cornell University, Ithaca, N. Y. Past-President, A.S.M.E.

Farmers and other agricultural laborers are credited with having a very great amount of freedom and self-determination in their work, but in spite of this, industry is found much fault with because it attracts so many of these people to its ranks.

Undoubtedly the principles of industrial democracy will help a great deal in stimulating interest among employees, depending not only upon the extent and fairness with which they are carried out but very largely upon the kind of industry affected; but before damning modern industrialism too much, it might be well to pause long enough to look back a hundred years and note that under the conditions prevailing, then every member of the family physically able to do so was in general obliged to work many more hours a day than he would have to today, in spite of which a family had far fewer of the comforts and conveniences of life that are so widely enjoyed at the present time.

For those who believe that all virtue lies in the organized workers, it is well to read this book in the order in which it is written; but to get the most benefit out of it, those who still maintain that some virtue rests in the owners and managers, should read a few of the concluding chapters first. Even then, however, it will be somewhat difficult when running across paragraphs, for instance, which express surprise and resentment over the courts' having decided that the primary purpose of a corporation is to make money, instead of, as the author, we presume, would have it, their first duty being to furnish pleasant and interesting employment the while the owners in some manner support themselves—just as there seems to be a widespread feeling that the owners of theaters, for one example, should furnish interesting entertainment at *low prices*, since entertainment is what the theaters are supposed to be organized for, and that it is a mere detail in the event of a deficit for the owners and managers of the theaters to make up any losses which may result.

A great advance will have been made when it is realized that both the workers and the owners are, in fact, organized into industry for service, and that they must use money as a medium of exchange and for convenience, in place of the old direct exchange of goods and products; and one of the reasons why workers, and very often the owners of industries as well, must give up a large portion of the results of their labor directly, or indirectly, is that it goes to the owners of land, or the holders of natural resources, who exact a large toll without, in most cases, having performed any service whatever.

Theo H. Miller.[1]

Books Received in the Library

Aircraft Year Book. 1924. Aeronautical Chamber of Commerce of America, Inc., New York, 1924. Cloth, 6 × 9 in., 339 pp., illus., diagrams, tables, $5.25.

A review of the technical and commercial advances and the important happenings in aviation during 1923. Both American and foreign advances are recorded, and many statistical data are tabulated. This series of annual summaries forms a convenient, useful record of achievement in the air.

Analytical Mechanics. By Edwin H. Barton. Second edition, revised and enlarged. Longmans, Green & Co., London and New York, 1924. Cloth, 6 × 9 in., 593 pp., diagrams, tables, $6.20.

A reasonably complete textbook on theoretical mechanics, intended for those possessing an elementary knowledge of the calculus. Includes the kinetics and statics of solids and of fluids, mechanisms and strains and elasticity. Covers the work required by degree candidates in British universities. This edition has been carefully revised and many new examples added.

Coal Carbonization. By Horace C. Porter, Chemical Catalog Co., New York, 1924. (American Chemical Society. Monograph series.) Cloth, 6 × 9 in., 442 pp., illus., diagrams, tables, $6.

Dr. Porter's book is mainly a description of the industrial equipment for carbonizing coal, of the methods of its operation and of the products obtained, together with an outline of the principles that underly the practical application of the process. Attention is also paid to the economic aspects of the carbonization of coal and a summary of the theory of the process is given. Special prominence is given to by-product coking, but gas making, low-temperature carbonization, and other branches are discussed. The book is primarily for the chemist and engineer interested in the principles and practice of carbonization, rather than for the engineer engaged in design, construction, or operation. The volume is a convenient summary of present knowledge in the field, prepared by an author with extensive practical experience.

Coal Industry. By A. T. Shurick. Little, Brown & Co., Boston, 1924. Cloth, 6 × 9 in., 383 pp., illus., $3.50.

An account of the industry as a whole, intended to present an accurate, comprehensive picture of its characteristic phases—occurrence, mining, distribution and economic conditions—unencumbered by too much detail or technical and statistical matter. Interestingly written and well adapted to meet the needs of the average man who wishes to understand the problems of the industry.

Engineering in American Industry. By Conrad Newton Lauer. McGraw-Hill Book Co., New York, 1924. Cloth, 9 × 12 in., 94 pp., illus., maps, charts, $2.50.

Mr. Lauer's rapid reconnaissance of the development of American industry since 1803 is particularly valuable for its numerous graphic charts. These are skilfully planned to show the industrial development of the country, decade by decade, the shifting of the centers of population and of manufactures, the relative rank of the leading industries, the production of the chief articles, the growth of railroads and other means of communication, etc. The illustrations, too, are excellent and illustrate forcibly the changes during the period.

Food Analysis. By A. G. Woodman. Second edition. McGraw-Hill Book Co., New York, 1924. (International Chemical series.) Cloth, 5 × 8 in., 529 pp., illus., tables, $3.50.

Prepared for use at the Massachusetts Institute of Technology, this text covers less ground than those commonly used, but contains more detailed discussion of the analytical processes involved and of their suitability and limitations. Greater emphasis is also laid on the interpretation of the analytical results. This new edition has been carefully revised.

Fuel Economy in Steam Plants. By Arthur Grounds. Isaac Pitman & Sons, London and New York, 1924. Cloth, 5 × 7 in., 106 pp., illus., diagrams, tables, 5s.

Discusses the losses that result from neglect of the process of burning coal and generating steam, showing how these losses may be obviated or reduced.

Fuel Oils and Their Applications. By H. V. Mitchell. Isaac Pitman & Sons, London and New York, 1924. Cloth, 5 × 7 in., 171 pp., illus., tables, 5s.

The uses range from steam raising and the heating of metallurgical furnaces to the production of power by internal-combustion engines and include stationary and traction service on land and the use of oil fuel at sea. Typical burners and oil-burning installations are described. The book will be useful as a clear, concise introduction to the subject and as a text for those who are concerned only with the basic technology of it.

Gasoline Automobile. By Ben G. Elliott and Earl L. Consoliver. Third edition. McGraw-Hill Book Co., New York, 1924. (Engineering Education series.) Cloth, 6 × 9 in., 513 pp., illus., diagrams, $3.

This popular textbook was planned for use in university extension work in Wisconsin, for the instruction of drivers, owners and salesmen. It aims to explain the mechanical principles which underly the operation of the automobile, to show how these principles are utilized in practice, and to give instructions for maintenance and repair. The new edition has been thoroughly revised.

International Cities and Town Planning Exhibition. English Catalog. Jubilee Exhibition, Gothenberg, Sweden. Paper, 7 × 10 in., 389 pp., illus., plans, $2.

The Jubilee Exhibition at Gothenberg in 1923 brought together an interesting collection of data on town planning from eighteen countries, and this catalog will be of interest to architects and

[1] Works Mgr., DeLaval Separator Co., Poughkeepsie, N. Y. Mem. A.S.M.E.

engineers, because of its historical and descriptive notes and its profuse illustrations. The latter include ancient and modern plans and pictures, showing the development of street and housing all over the civilized world.

LINEAR INTEGRAL EQUATIONS. By William Vernon Lovitt. McGraw-Hill Book Co., New York, 1924. Cloth, 6 × 8 in., 253 pp., $3.

Presents in a readable, systematic manner the general theory of linear integral equations, with some of its applications to differential equations, the calculus of variations, and some problems in mathematical physics. These include problems in vibration and in the flow of heat in a bar.

MINERS' WAGES AND THE COST OF COAL. By Isador Lubin. McGraw-Hill Book Co., New York, 1924. (Institute of Economics. Investigations in Industry and Labor.) Cloth, 5 × 8 in., 316 pp., $2.50.

This is the first of a series of studies on coal, which has been undertaken by the Institute of Economics with a view to focusing public attention on the significant aspects of the coal problem. It attempts to analyze the wage system that has been developed in the bituminous-coal industry and to show how this system has affected the earnings of the miners, the cost of producing coal and the exploitation of our coal resources.

PLANNING, ERECTION AND OPERATION OF MODERN OPEN HEARTH STEEL WORKS. By Hubert Hermanns. Ernest Benn, Ltd., London, 1924. Cloth, 7 × 10 in., 307 pp., illus., diagrams, tables, 42s.

Although there are numerous works on open-hearth steel, they are principally concerned with the metallurgy of steel production and neglect the aspects of the subject which are considered in the present book. It is concerned with the planning and design of the steel plant, the handling and transport of materials, and with heat efficiency. Mechanical appliances for these purposes are described in detail and much suggestive discussion of steel-works problems is given. Covering a new field as it does, the book has great interest. The work is based on German practice.

PORTLAND CEMENT PRICES. By Henry P. Willis and John R. B. Byers. Ronald Press Co., New York, 1924. Cloth, 5 × 8 in., 123 pp., charts, tables, $1.25.

The authors of this work are respectively professor of banking in Columbia University and instructor in economics in the College of the City of New York. At the behest of various large producers who have wished to present the facts to the public, they have made a careful examination of price quotations and other data, which are presented here, together with their conclusions. The book is a survey of the position, history and elements of the present price of Portland cement, intended to explain the way in which prices are determined, changed and regulated by economic conditions, and to apply tests which may serve as a basis for a judgment of their character.

PRINCIPLES OF RAILWAY TRANSPORTATION. By Eliot Jones. Macmillan Co., New York, 1924. Cloth, 6 × 9 in., 607 pp., $3.50.

Contents: Part 1, Introduction. Part 2, Rates and rate making. Part 3, Legislation upon entrance of the United States into the World War, April, 1917. Part 4, Some railroad problems. Part 5, Railroads and the war. Part 6, Railroads and reconstruction.

Designed primarily as a text for elementary courses, this book aims to set forth the essentials of the railroad problem with clearness, accuracy and impartiality. General readers will also find it useful as a statement of the essential background of the railroad problem, which will aid them to obtain an unbiased understanding of the fundamentals of the situation.

PROPERTIES AND USES OF WOOD. By Arthur Koehler. McGraw-Hill Book Co., New York, 1924. (Industrial Education series.) Cloth, 6 × 9 in., 354 pp., illus., tables, $3.50.

Intended to present, in as non-technical a manner as is consistent with clearness and accuracy, the properties of wood and their influence upon its utilization. The structure and physical, mechanical, and chemical properties of wood are set forth and the factors that affect the strength of wooden members are explained. There are also chapters on seasoning and drying, on deterioration and protection against decay and fire, and on various economic aspects of the lumber industry.

QUANTITATIVE ANALYSIS. By Edward G. Mahin. Third Edition. McGraw-Hill Book Co., New York, 1924. (International Chemical series.) Cloth, 6 × 8 in., 595 pp., illus., tables, 8 × 6 in., $4.

This text is designed to cover the ground usually covered in a college course, with a sufficient latitude for wide selection of examples, and at the same time to present an adequate theoretical and practical discussion of the subject. The book includes general quantitative analyses, the special quantitative measurements usually made in chemical laboratories, and the special methods for the analysis of industrial products and raw materials. New matter has been added in this edition, which has also undergone general revision.

RAILWAY RATES AND COST OF SERVICE. By Owen Ely. Houghton Mifflin Company, Boston and New York, 1924. Cloth, 5 × 8 in., 148 pp., $2.

A study of this important problem from the economic point of view. The author examines the work and policies of the Interstate Commerce Commission and recent rate regulation. He then analyzes the rate theories advanced by students of transportation, following this by a study of the relation between operating costs and rates, and an examination of the attempts which have been made to develop a technique of cost accounting. He finally draws conclusions as to the efficiency of the present rate system, socially and economically, and as to the proper program of rate reconstruction.

RELATIVITY AND GRAVITATION. By T. Percy Nunn. University of London Press, London, 1923. Cloth, 5 × 8 in., 162 pp., $2.40.

Most books upon this theory are either expositions intended for readers with no mathematics, or else serious treatises presupposing considerable technical training. This publication occupies a middle ground. It is intended for the layman who has had the usual college training in mathematics, but the demonstrations are given with an unusual fullness and the use of the tensor calculus is avoided.

SCALES AND WEIGHING, THEIR INDUSTRIAL APPLICATIONS. By Herbert T. Wade. Ronald Press Co., New York, 1924. Cloth, 6 × 9 in., 473 pp., illus., diagrams, $6.

This book describes the various types of weighing machines which are available for industrial use and their advantages and limitations, and gives examples of their use in various industries and for special purposes. It is intended as a guide in the selection, use and maintenance of scales, and is a welcome addition to the short list of books which is available on the subject. A bibliography is included.

SHIP JOINERY; the Woodwork Fitting of a Modern Steel Vessel. By S. G. Duckworth. E. P. Dutton, New York, 1924. Cloth, 6 × 9 in., 215 pp., illus., $2.50.

A detailed description of these fittings and furniture, with complete directions for making them and working drawings. While intended primarily for joiners, it may interest designers also as an indication of modern practice in equipping and furnishing passenger liners.

TECHNISCHE MECHANIK STARRER GEBILDE, Vol. 1; Mechanik Ebener Gebilde. By Hans Lorenz. Julius Springer, Berlin, 1924. (Lehrbuch der technischen physik, vol. 1.) Boards, 6 × 9 in., 390 pp., diagrams, $4.30.

A carefully planned treatise on the technical mechanics of rigid plane structures, based on long experience in teaching the subject in technical high schools. The book is intended for beginners who have but a general knowledge of principles, and to these it offers a thorough course in condensed form. In the section on statics, graphic methods are given equal prominence with analytical ones.

THEORY AND PRACTICE OF PUBLIC UTILITY VALUATION. By W. H. Maltbie. McGraw-Hill Book Co., New York, 1924. Cloth, 6 × 8 in., 201 pp., $2.

A discussion of the principal points in the theory and practice of the valuation of public utilities. The book is not intended for specialists but for the general public and is written in a way which will be intelligible to the latter.

THE ENGINEERING INDEX

Registered United States Great Britain and Canada

Exigencies of publication make it necessary to put the main body of The Engineering Index (p. 135-EI of the advertising section) into type considerably in advance of the date of issue of "Mechanical Engineering." To bring this service more nearly up to date is the purpose of this supplementary page of items covering the more important articles appearing in journals received up to the third day prior to going to press.

AUTOMOBILES

Transmissions. A Study of an Unusual Transmission, J. Younger. Am. Mach., vol. 61, nos. 9 and 10, Aug. 28 and Sept. 4, 1924, pp. 337–340 and 375–377, 17 figs. Description of method of functioning of Chandler transmission and some of the manufacturing operations on it.

AXLES

Design. Outstanding Tendencies in Axle Design, W. F. Rockwell. Soc. Automotive Engrs.—Jl., vol. 15, no. 3, Sept. 1924, pp. 189–194, 7 figs. Discusses semi-floating type of axle, worm-drive passenger-car axles, motor-truck rear-axle types, unsprung weight, and future car and truck axles.

BELTING

Materials. Belting Materials, G. A. Frenkel. Machy. (N. Y.), vol. 31, no. 1, Sept. 1924, pp. 14–16, 1 fig. Physical properties and general characteristics of leather, rubber, cotton, and steel belting.

BLAST-FURNACE GAS

Cleaning. Electric Cleaning of Blast Furnace Gas. Iron Age, vol. 114, no. 9, Aug. 28, 1924, pp. 502–503. Analysis of losses incurred by releasing latent and sensible heat of gases. Comparison with manufactured gas and its sales value.

BOILER FEEDWATER

Treatment. The Boiler-Water Problem, W. M. Booth. Power, vol. 60, no. 1, Sept. 9, 1924, pp. 410–412. Outlines in non-technical language some of the principal things an engineer should consider in insuring a supply of suitable feedwater for his boilers.

BOILER FURNACES

Down-Draft Hand-Fired, Firing of. Firing a Hand-Fired Down-Draft Furnace, J. F. Barkley. Power Plant Eng., vol. 28, no. 17, Sept. 1, 1924, pp. 890–891. Method reported by Bur. Mines for developing high boiler ratings from down-draft furnaces.

Water-Cooled. Water-Cooled Furnaces Make Records at Hell Gate, W. E. Caldwell. Power, vol. 60, no. 10, Sept. 2, 1924, pp. 354–358, 6 figs. Side walls made of 4-in. tubes with overlapping fins; furnace deterioration greatly reduced; combined efficiency of 92.7 per cent obtained.

CABLEWAYS

Explosives Handling, for. A Ropeway for Explosives. Engineer, vol. 138, no. 3578, July 25, 1924, pp. 102–104, 15 figs. partly on supp. plate. Describes arrangement of ropeway installed at explosives factory of Cookes Explosives, Ltd., Penrhyndeudraeth, North Wales, for purpose of conveying materials from one to another of the several isolated huts where the various processes are carried on, and also for taking finished materials to a magazine on top of a hill. Difficulties which had to be overcome in designing line.

CASTINGS

Production. Producing High Test Castings. Foundry, vol. 52, no. 17, Sept. 1, 1924, pp. 681–683, 5 figs. Exacting methods employed in producing special lines of castings to comply with rigid specifications. Care exercised in mixtures used, and pouring temperatures.

CENTRAL STATIONS

Industrial Power Plants vs. Central Station vs. Industrial Power Plants, W. J. Risley, Jr. Power Plant Eng., vol. 28, no. 17, Sept. 1, 1924, pp. 896–897. Factors to be considered in making a change from one form of service to another.

Iron River, Mich. Diesel-Engine Stand-by Plant at Iron River, Michigan. Power, vol. 60, no. 11, Sept. 9, 1924, pp. 390–393, 3 figs. Describes a two-unit Diesel plant of 2150 kva. capacity installed to supplement water power in preference to addition to existing steam plant; cost 187.74 per kilowatt; economy 0.675 lb. oil per kilowatt-hour.

Oil-Engined, Operation of. Systematic Methods for Oil Engine Plants. Power Plant Eng., vol. 28, no. 17, Sept. 1, 1924, pp. 893–894, 2 figs. Prime Movers Committee of Nat. Elec. Light Assn. stresses value of definite maintenance procedure and record systems.

CHAINS

Roller, High-Speed. High-Speed Roller Chains, G. M. Bartlett. Machy. (N. Y.), vol. 31, no. 1, Sept. 1924, pp. 22–23, 2 figs. Discusses limits of permissible chain velocities.

DIESEL ENGINES

Worthington. Diesel Engine with Power at Every Stroke. Iron Age, vol. 114, no. 10, Sept. 4, 1924, pp. 559–560, 2 figs. Particulars of Worthington development of two-cycle double-acting prime mover which promises notable widening of oil-engine field in applicability and economy.

FOUNDRIES

Cost Finding. Finds Costs by Uniform Method, R. E. Belt. Iron Trade Rev., vol. 75, no. 10, Sept. 4, 1924, pp. 604–606. Benefits derived from uniformity of methods for determining production costs are shown by bids received on malleable castings before and after system was adopted. Some bids found to be below cost.

Pulverized Coal Burning. Adopt Powdered Coal System. Foundry, vol. 52, no. 17, Sept. 1, 1924, pp. 667–670, 6 figs. Experience of malleable-iron foundry of Am. Radiator Co., Buffalo, N. Y., with powdered coal burning for melting and annealing castings. Advantages claimed as result include neatness and economy and a considerable reduction in cost.

FURNACES, HEAT-TREATING

Continuous. Continuous Heat-Treating Furnaces, H. M. Groff. Machy. (N. Y.), vol. 31, no. 1, Sept. 1924, pp. 10–12, 3 figs. Describes small furnace of bench type for hardening and tempering round wire or flat stock of the smaller sizes, and a furnace for handling individual parts. Both may be gas or electrically heated.

HYDROELECTRIC DEVELOPMENTS

Ontario, Canada. Queenston-Chippawa Development of the Hydro-Electric Power Commission of Ontario, F. A. Gaby. Engineering, vol. 118, nos. 3059 and 3060, Aug. 15 and 22, 1924, pp. 220–223 and 255–257, 23 figs. partly on supp. plates. Outline of a number of salient engineering and other features involved in design and construction of Queenston-Chippawa development. Deals with intake, canal, screen house, penstocks, generating and transformer station, turbines, Johnson valves, governors and generators.

INDUSTRIAL MANAGEMENT

Prague Congress. Congress on Management Held at Prague. Iron Age, vol. 114, no. 9, Aug. 28, 1924, pp. 500–501. Presentation of American methods for benefit of nations of central Europe. Nature of scientific management, human element in management, budget and production control, education for management, Skoda and Witkowitz works.

LOCOMOTIVES

Construction, France. Building Locomotives in France, V. Delport. Iron Trade Rev., vol. 75, no. 10, Sept. 4, 1924, pp. 600–603, 4 figs. Methods used at works of Société Française de Constructions Mécaniques, at Denain.

MACHINE SHOPS

Jobbing Work. Job Work Manufacturing Problems, E. W. Leach and J. T. Koch. Am. Mach., vol. 61, no. 11, Sept. 11, 1924, pp. 411–413. Discussion of factors to be considered in establishment of a jobbing department in a machinery plant.

MACHINING METHODS

Side- and Main-Rod Work. Side and Main Rod Work, L. C. Morrow. Am. Mach., vol. 61, no. 10, Sept. 4, 1924, pp. 367–369, 5 figs. Methods of West Albany shops of New York Central R. R. with description of an air-operated fixture used in machining rod brasses.

MATERIALS HANDLING

Hopper Design. Hopper Design for Automatic Machinery, A. A. Dowd. Machy. (N. Y.), vol. 31, no. 1, Sept. 1924, pp. 37–40, 6 figs. Consideration of design of types of hoppers most commonly required. Examples of hopper design.

METALS

Fatigue. The Work of the Fatigue Panel of the Aeronautical Research Committee, C. F. Jenkin. Engineering, vol. 118, no. 3059, Aug. 15, 1924, p. 245. Describes nature of problem that panel appointed to investigate problem of fatigue in metals is endeavoring to solve and the various lines of investigation which are being followed. Paper read before Sec. G of British Assn. at Toronto.

SEMI-DIESEL ENGINES

Operation. Semi-Diesel Operation at All Load Ratings, H. F. Shepherd. Power, vol. 60, no. 10, Sept. 2, 1924, pp. 366–368, 3 figs. Discusses variable operating characteristics through load range and gives scavenging as most important factor in this variation. Calculations for a two-stroke engine with compression of 180 lb. gage.

STEAM

Generation, United States Practice. Present Practice in Steam Generation in the United States, D. S. Jacobus. Power, vol. 60, no. 10, Sept. 2, 1924, pp. 368–370. Effect of many passes, use of air heaters, relation of efficiency to furnace temperature, etc. Extract of paper read before First World Power Conference, Lond.

STEEL

Carbon. The Structure of Troostite and Sorbite, O. V. Greene. Iron Age, vol. 114, no. 11, Sept. 11, 1924, pp. 615–617 and 670, 10 figs. Results of investigation whose purpose was development of actual structures of complex constituents of carbon steels; steels used were quenched and drawn at various temperatures that had been arranged with a view of producing troostite and sorbite in them; physical tests were used to correlate microstructure with physical properties.

Partly Killed. Partly Killed Simple Steels, H. D. Hibbard. Iron Age, vol. 114, nos. 10 and 11, Sept. 4 and 11, 1924, pp. 565 and 599–600, and 631–633. Comparison with killed and effervescing steels; gas holes and their effects; advantages of two heatings and rollings; settling and rising low-carbon and medium steels; steel for structural uses and for rails.

Testing. Inspects Stock by Brinell Test. Iron Trade Rev., vol. 75, no. 11, Sept. 11, 1924, pp. 666–667, 7 figs. Notes on special test developed in laboratories of Steel Products Co., Cleveland, O., which is applied to inspection of material purchased for either hot or cold heading and subject to surface seams, pits, cracks, laps, improper anneal, etc.; developed as result of experiments to determine relative qualities of electric furnace and crucible steel for automotive poppet valves. Hardened cone used instead of ball.

STEEL, HEAT TREATMENT OF

Springs. Heat-treatment of Steel Springs, J. W. Rockefeller, Jr. Machy. (N. Y.), vol. 31, no. 1, Sept. 1924, pp. 4–5, 2 figs. Factors that affect heat treatment; recommended heat treatments. Deals also with heat treatment for alloy steel springs.

STEEL MANUFACTURE

Acid Bessemer. Acid Bessemer Practice in Sweden. Iron Age, vol. 114, no. 11, Sept. 11, 1924, pp. 637–638, 4 figs. Process carried out without final additions; converters distinctly unique; heat balance and composition of iron and steel. Abstract from article by R. von Seth in Jernkontorets Annaler, no. 1, 1924.

STEAM POWER PLANTS

Economy. The Industrial Power Plant, E. Douglas. Power, vol. 60, no. 11, Sept. 9, 1924, pp. 394–395. Its possibilities and place in our economic structure.

STEAM TURBINES

Cross-Compound. Cross-Compound Impulse Turbine Geared to 4,000-kw. D.-C. Generator. Power, vol. 60, no. 10, Sept. 2, 1924, pp. 360–362, 3 figs. Describes De Laval units installed for auxiliary drive in Trenton Channel Plant of Detroit Edison Co.; each unit contains two d.-c. generators operating in parallel at 250 volts, capable of delivering 4000 kw. at normal load and 6000 at maximum. Reduction gears used between turbine and generator, and principle is developed as so to include both high- and low-pressure turbines, driving a common gear through individual pinions. Advantages thus obtained.

Lubrication. Improving the Lubrication System of Steam Turbines, C. C. Brown. Power, vol. 60, no. 11, Sept. 9, 1924, pp. 420–422, 1 fig. Describes oil troubles, their causes in steam turbines, and how application of a cooling coil and a slow reciprocating steam pump eliminated them from a continuous filtration system.

Tests. Tests of a 7,000-Kw. Steam Turbine Generator at the Bristol Electricity Works. Engineering, vol. 118, no. 3060, Aug. 22, 1924, pp. 253–255, 6 figs. Report of exhaustive tests of a 7000-kw. machine at Bristol, Eng., which have been carried out by Metropolitan-Vickers Elec. Co., Ltd., Manchester; main object of test was to establish by actual figures real efficiency of multiple exhaust arrangement, which is now embodied in all large turbines constructed by firm in question.

STEEL WORKS

Mill Electrification. Electrifying Ten-Inch Merchant Mill, M. J. Wohlgemuth and M. H. Morgan, Jr. Elec. Wld., vol. 84, no. 10, Sept. 6, 1924, pp. 465–468, 6 figs. How electric drive replaces engine drive at McKeesport, Pa., works of Firth-Sterling Steel Co., to produce cutlery without marking and without reheating. Details of installation and control.

STOKERS

Underfeed. How to Regulate Underfeed Stokers, J. E. Richardson. Power, vol. 60, no. 11, Sept. 9, 1924, pp. 401–402, 1 fig. Practical points on reducing combustible in ash, balancing stack loss against ashpit loss, proper speed for clinker grinders and other conditions bearing on efficiency of combustion.

TRACTORS

Applications. Industrial and Commercial Applications of the Tractor, G. D. Babcock. Soc. Automotive Engrs.—Jl., vol. 15, no. 3, Sept. 1924, pp. 199–205, 16 figs. Heat treating of track shoes; lubrication of track; variation of size of calks; use, with tractors, of various accessories, such as rotary snow plows, timber-cutting machines, road graders and scrapers, and operations such as scarifying of old ashpalt, Southern logging and swabbing of oil wells, are described.

VALVES

Butterfly. New Type of Butterfly Valves Used on Davis Bridge Hydro-Electric Project. Power, vol. 60, no. 10, Sept. 2, 1924, pp. 358–359, 3 figs. Describes improved type of butterfly valve, known as Dow disk-arm pivot valve, which has been extensively used on New England Power Co.'s Davis Bridge project. Represents an attempt to retain simplicity and moderate cost of usual type of butterfly valve and at same time provide an operating mechanism of such type and rigidness as to increase reliability and reduce leakage.